NASA ESTO Instrument Incubator Program

Microwave Observatory of Subcanopy and Subsurface(MOSS): Final Results and Next Steps

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Astro Aerospace

MOSS

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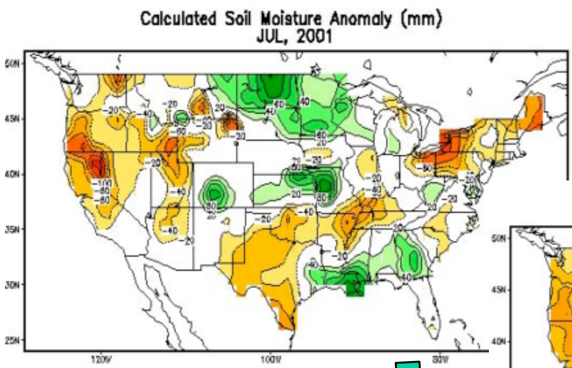
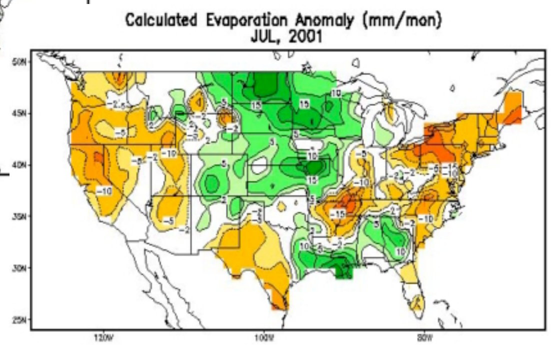
Project Overview

MOSS Concept

- MOSS addresses a key research issue for the Global Water and Energy Cycle: **measuring soil moisture under "substantial vegetation canopies and at useful soil depths"**
- The proposed system is a UHF/VHF SAR that delivers data for estimation of soil moisture
  - down to 1-5m depth
  - through 200 tons/ha or more of vegetation
  - at 1-Km resolution
  - globally once every 7-10 days.
- Key hardware technology challenge is a low-mass, low-risk, 30-m long antenna aperture and associated feed system that operate at two frequencies with two different effective narrow aperture widths

Science Significance

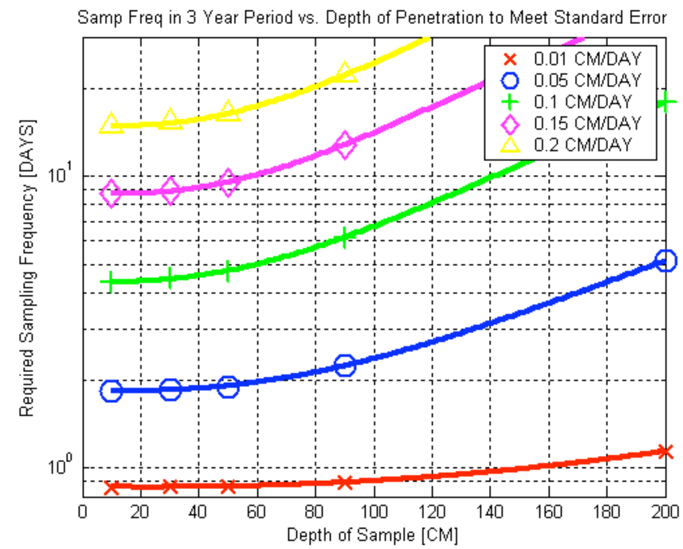




- Soil moisture profile down to the root zone controls global hydrologic partitioning into evaporation, transpiration, runoff, and drainage.
- Quantifying evaporation is required to address ESE priority science questions about the water cycle as well as the carbon cycle:

> Is the water cycle accelerating due to global change?

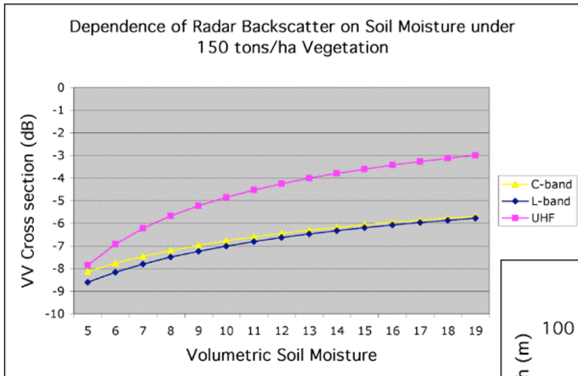
> What is the magnitude of carbon sequestration in global forests (a major portion of the 'missing sink')?

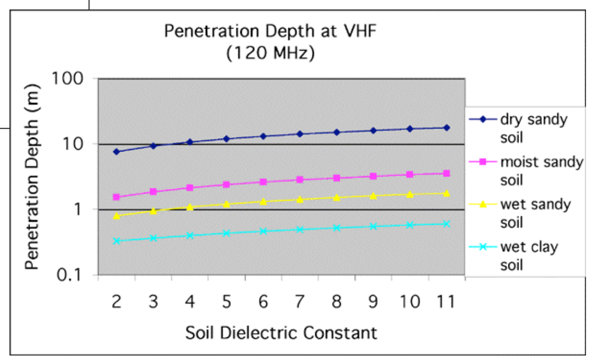


- Observed soil moisture (%) shows that depletion of moisture by evaporation extends deep into the soil.
- Deep moisture sampled at longer intervals (7-10 days) has the same impact on water balance estimation as surface/shallow soil moisture sampled rapidly (2-3 days).

Entekhabi/Salvucci

Choice of Radar System Parameters





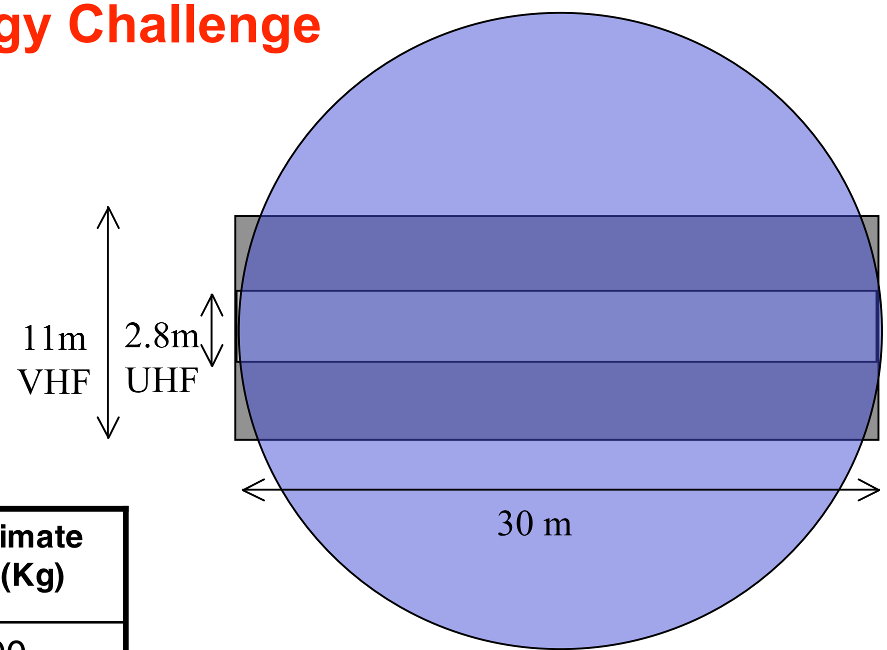
- For the same vegetation cover, lower frequencies show higher sensitivity to integrated soil moisture

Parameter	UHF	VHF
Altitude	1313 km	1313 km
Swath Width	346 km	346 km
Antenna Width	2.8m	11m
Antenna Length	30m	30m
Center Frequency	435 MHz	137 MHz
Bandwidth	1 MHz	1 MHz
No.Looks/1km (min.)	54	40
Peak Power (1 channel)	2kW	2 kW
Pulse Length	140usec	140usec
Duty Cycle (2 channel)	13%	13%
Avg. Power (2 channel)	255W	255W
PRF (1 channel)	455Hz	455Hz
Processing Bandwidth	137Hz	182Hz
Data Rate (dual channel)	1.7Mbps	1.7Mbps
Incidence Angle Range	16-32	16-32
Azimuth Ambiguities	-18dB	-20dB

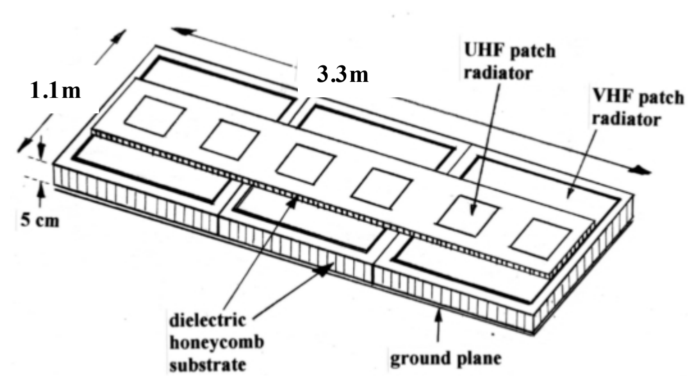
- At least two frequencies are needed to separate effects of vegetation and soil
- Polarimetry at each frequency is needed to sufficiently characterize vegetation and soil
- It has been shown that optimum soil penetration depths are achieved for frequencies between about 100MHz - 500 MHz.

Key Technology Challenge

- Key hardware technology item for a future spaceborne mission is the 30-m long, dual-width antenna
- Mass savings of our approach over current technology is ten-fold
- Significantly lower risk than other proposed technologies such as inflatable apertures



Antenna Implementation	Approximate mass (Kg)
Two planar arrays (30mx3m and 30mx11m), state-of-technology (LightSAR), 10kg/m^2	4200
Dual-frequency shared aperture planar array, state-of-technology (lightSAR) shared segment (30mx3m): 15kg/m2, remaining segment (30mx8m): 10kg/m2	3750
Passive mesh reflector with dual-frequency feed (this IIP concept), 15kg/m2 for feed, ~300 Kg for 30m mesh reflector	~ 400

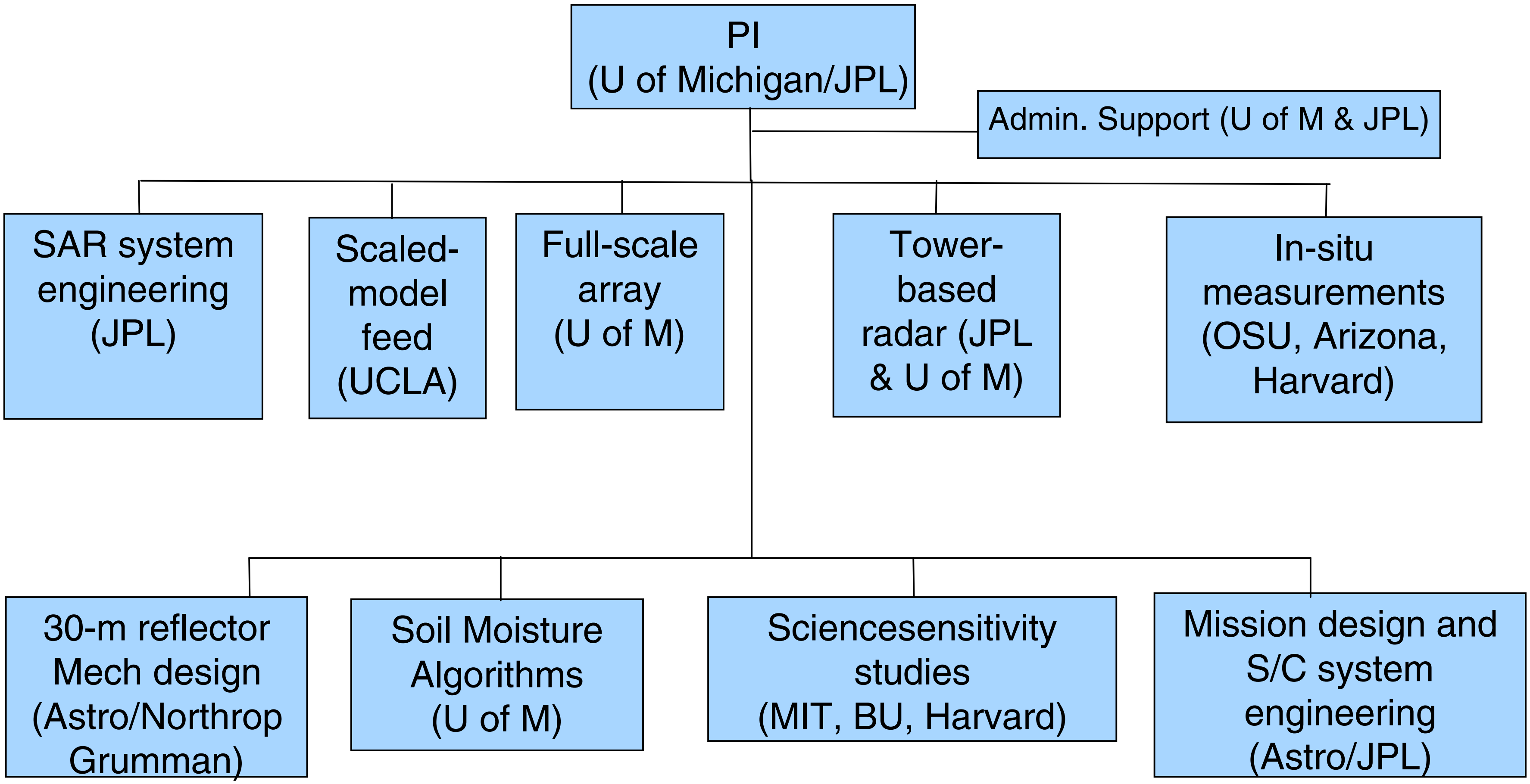


Dual-stacked patch feed for synthesizing highly shaped apertures on reflector

Project Goals

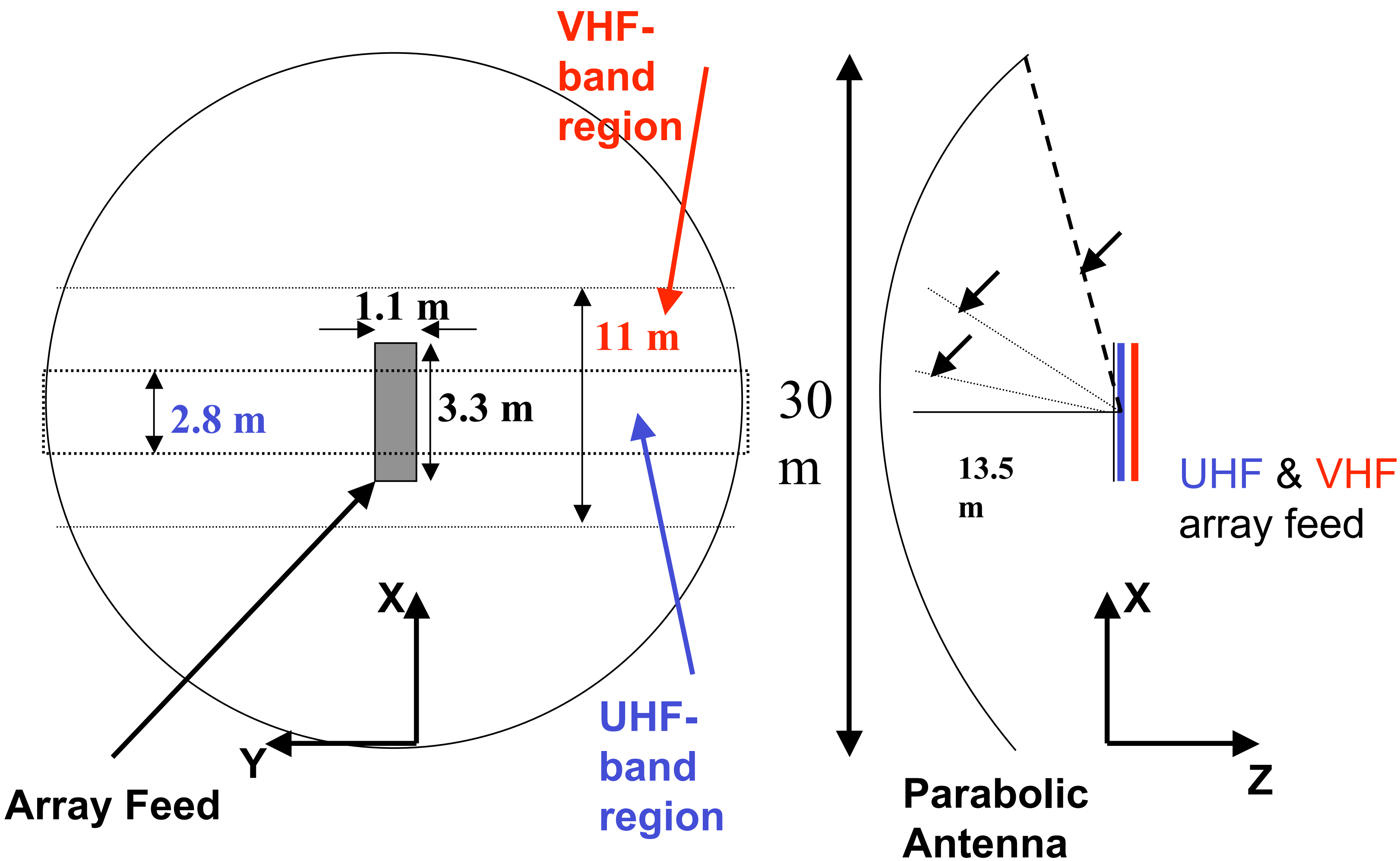
- **Antenna design and feed prototype**
  - Design, build, and test a complete scaled model of the shared planar array single feed structure
  - Design, build, and test the full-size feed structure
  - Generate the 30-m reflector antenna and S/C mechanical design
- **Demonstrate science data and soil moisture products**
  - Construct a validation science data set through ground experiments and tower radar
  - New-generation low-frequency radar soil moisture estimation algorithms
- **Investigate compensation of ionospheric effects**
- **Assess impact on global change studies**
  - Test the sensitivity of hydrological cycling models to soil moisture products from this instrument set
  - Assess impact of products on ecological and global change studies
- **Address spectrum management issues**

Team Organization



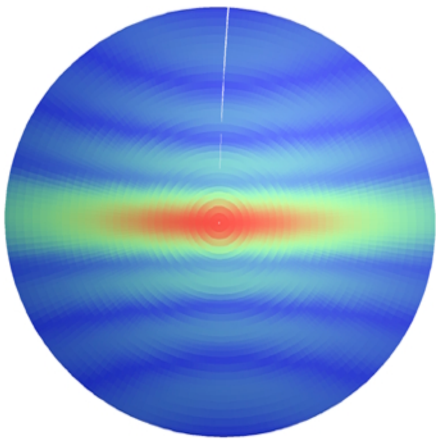
Dual-band Dual-pol Antenna Feed System

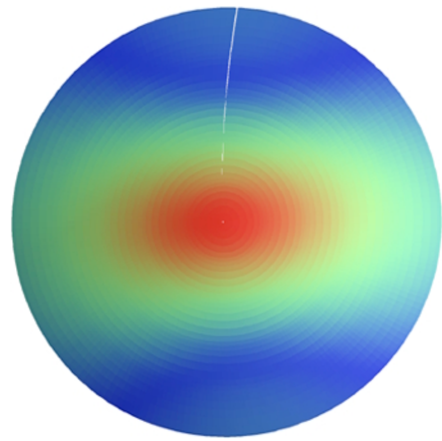
30-m Reflector Antenna and Feed Geometry

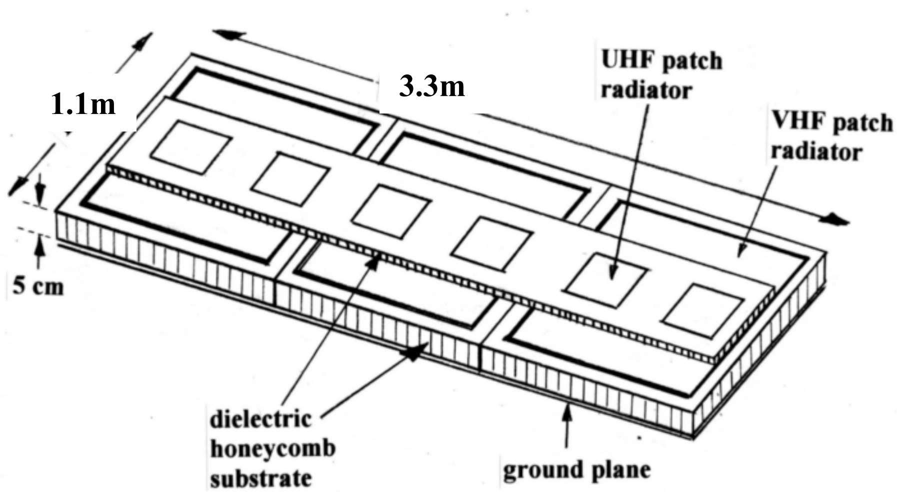


F/D=0.45

Dual-band Stacked Patch Configuration and Resulting Reflector Currents



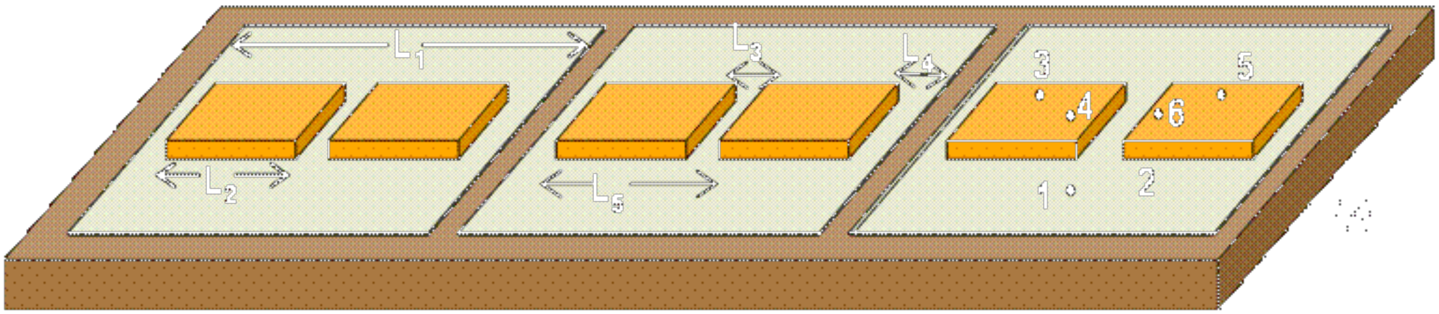




Huang/YRS

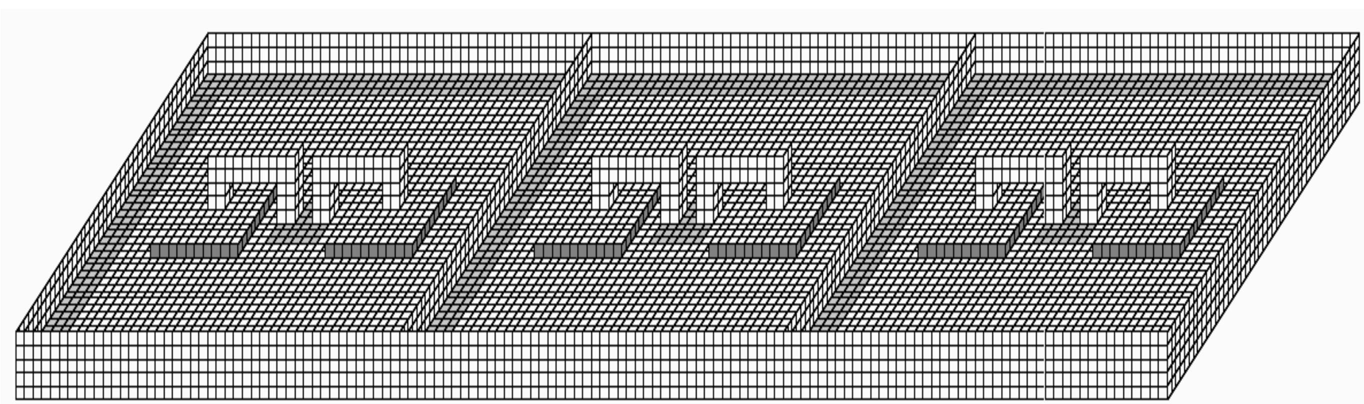
Scaled Frequency Antenna Feed

Scaled array dimensions



Port 1: H-port Lower Patch
Port 2: V-port Lower Patch
Port 3: V-port Upper Patch
Port 4: H-port Upper Patch
Port 5: V-port Upper Patch
Port 6: H-port Upper Patch

Complete Array Dimensions for Frequencies: 1.13GHz, 3.57GHz



Computational model used in FDTD code

Array Antenna Dimensions

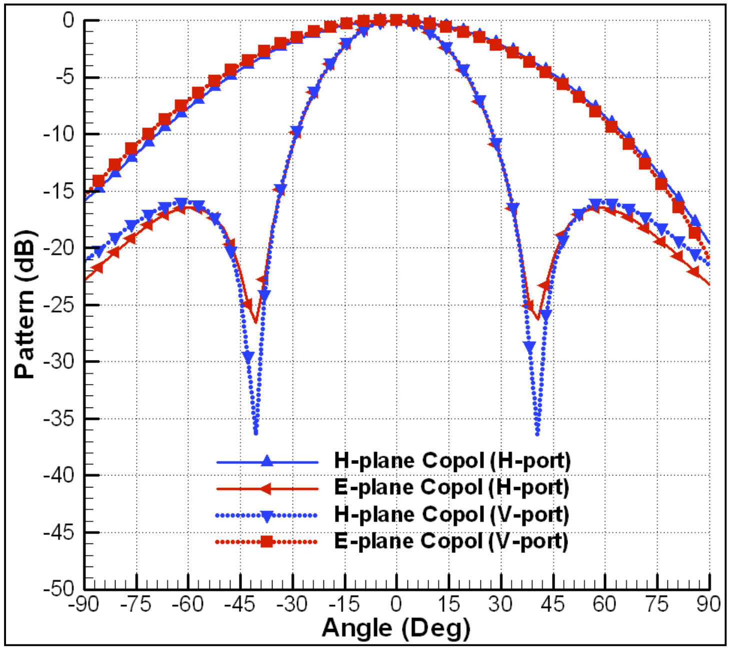
L = 39.9 cm,
W=13.3cm
L_1 = 11.5 cm,
L_2 = 2.95 cm,
L_3 = 3.2 cm,
L_4 = 0.9 cm,
L_5 = 6.15 cm

Substrate thickness:
Lower patch = 6mm,

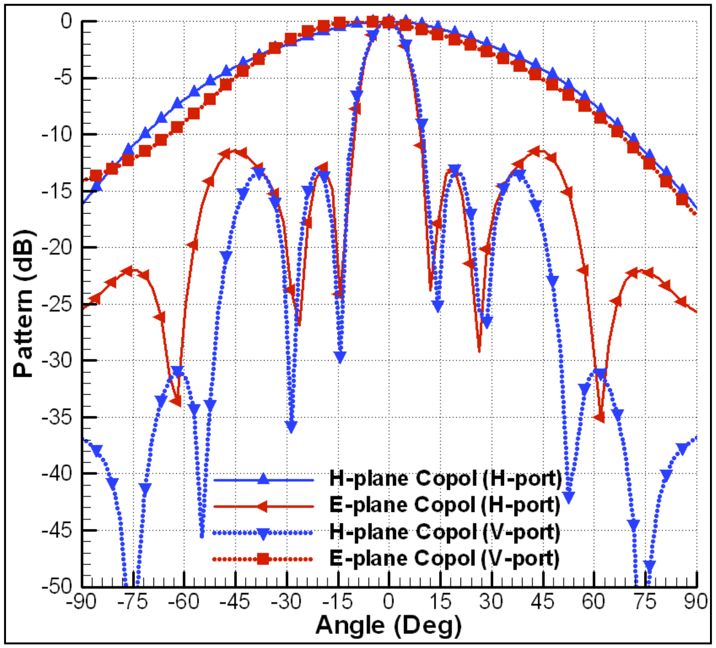
Substrate thickness:
Upper patch = 3mm

Dielectric constant
Upper patch: 2.2

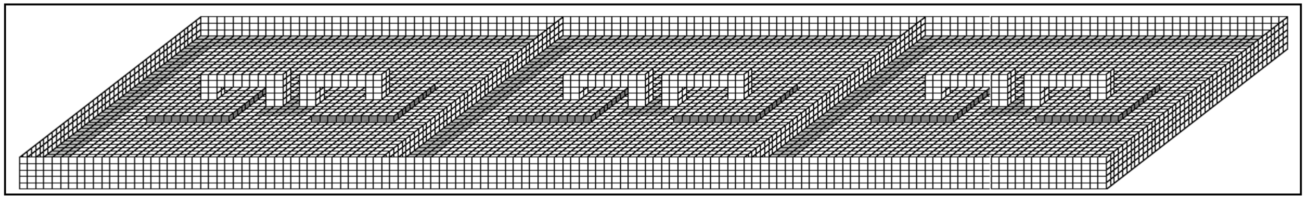
FDTD Simulated Radiation Pattern of the Stacked Patch Array

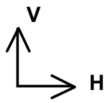


Simulated Pattern: Lower-Patches



Simulated Pattern: Upper-Patches



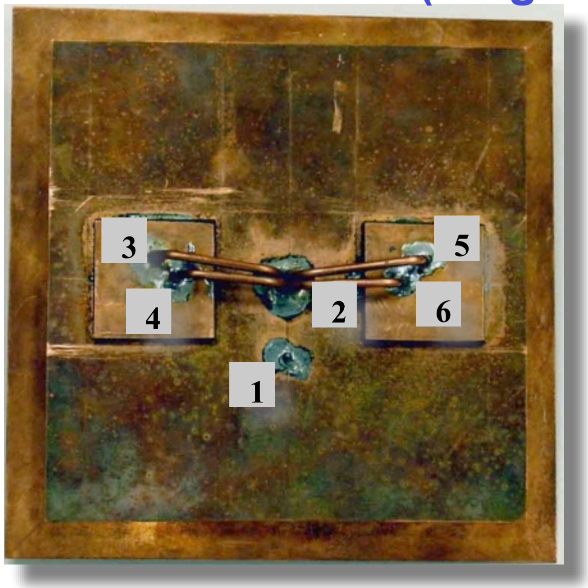


- Similar beamwidths and nulls for the two orthogonal polarizations for lower patch in the principal planes.
- Similar beamwidths but slight shift in null positions for the two orthogonal polarizations is observed.

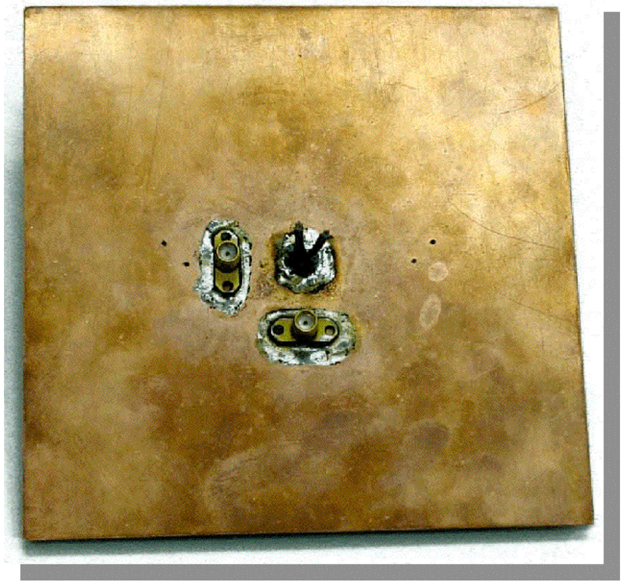
Scaled Frequency Antenna Feed

Dual-Frequency Dual-Polarized Stacked Microstrip Patch

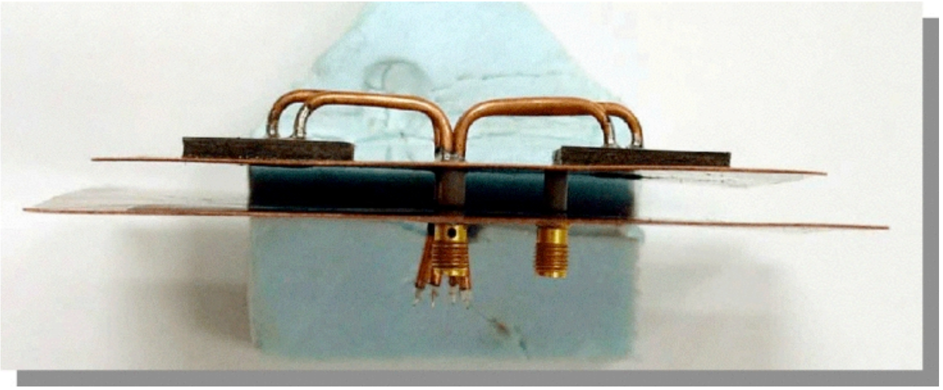
(Single Element of the Array)



Top view



Bottom view



Side view

A novel stacked probe-fed architecture with side-feeding is used to obtain dual-frequency and dual linear polarization

YRS

Scaled Frequency Antenna Feed

Front-View of the Array

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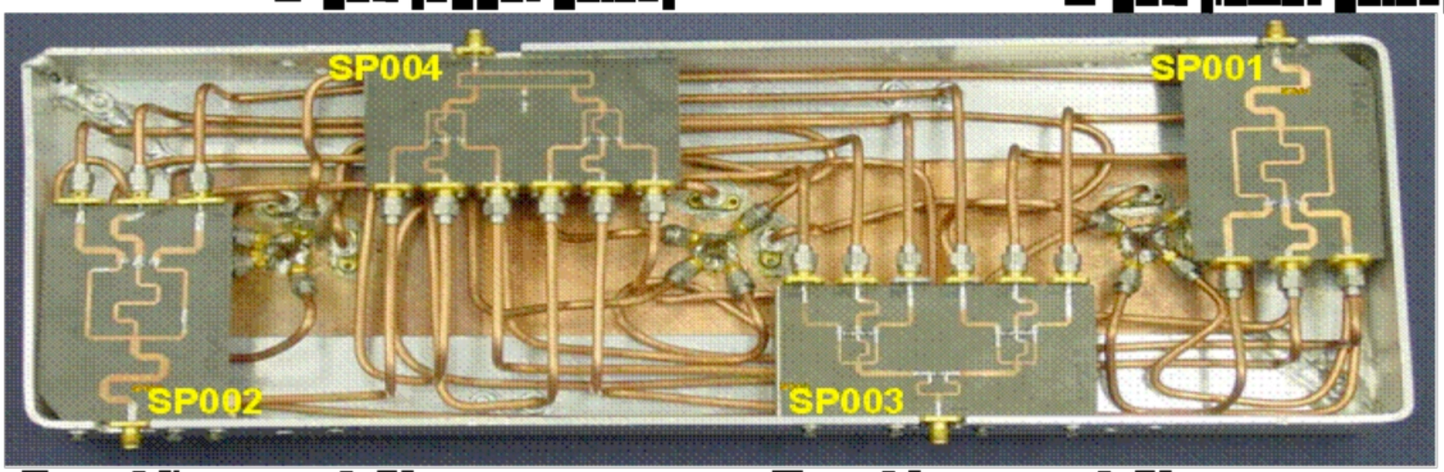

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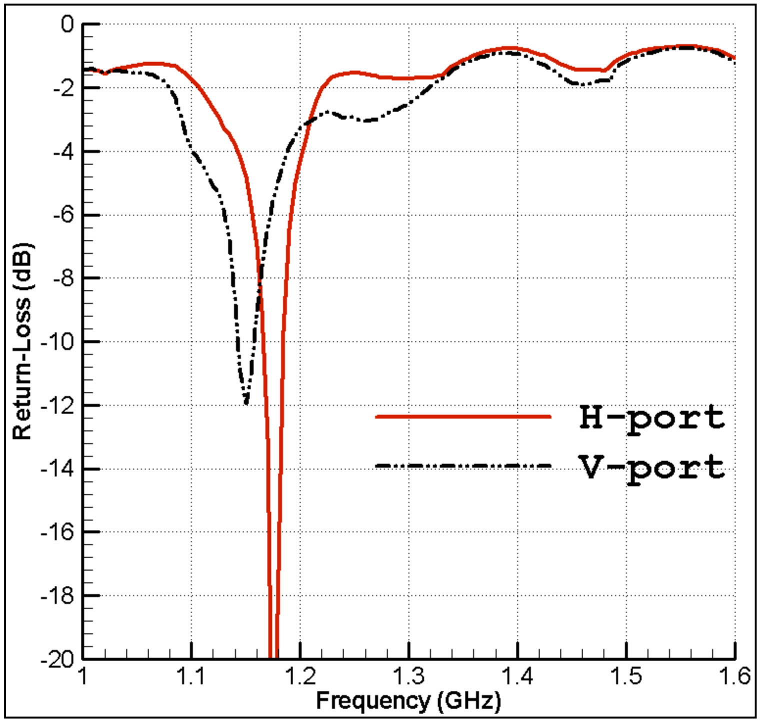
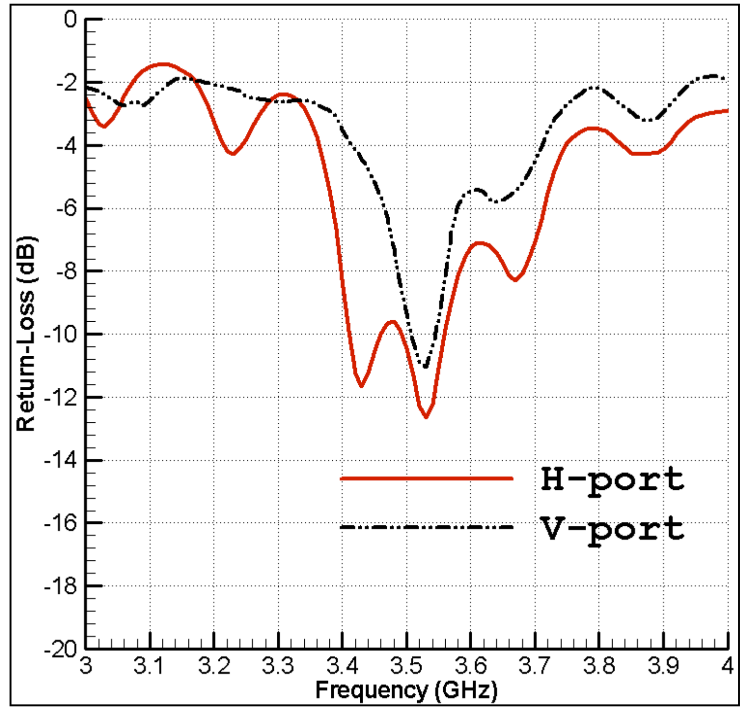
Back -View of the Array

Return-Loss Measurement Results for Array



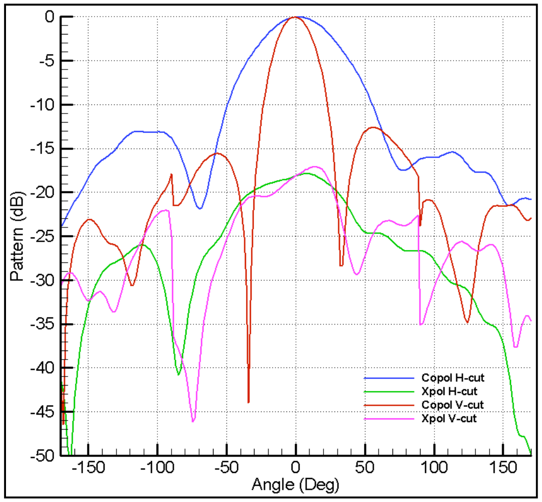
Measured Return-Loss: Lower-Patches



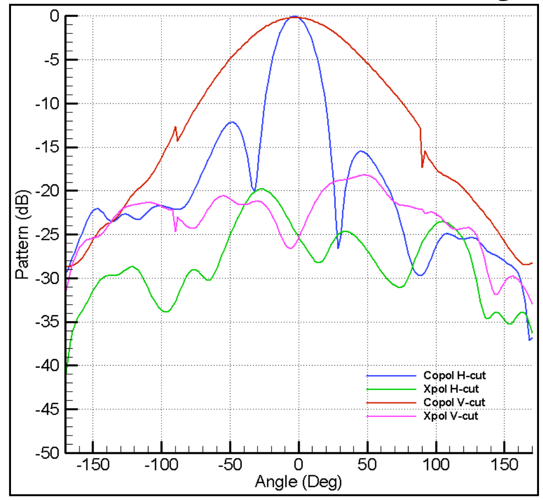
Measured Return-Loss: Upper-Patches

- Common operation point for the two-ports of lower-patch is at 1.16GHz frequency.
- Common operation point for the two-ports of upper-patch is at 3.53GHz frequency.
- These frequencies are used for testing against the reflector instead of the actual 1.13GHz and 3.57GHz.

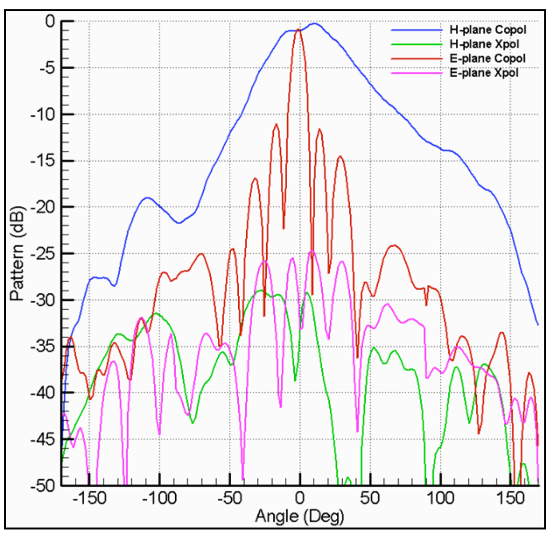
Radiation Pattern Measurement Results for Array



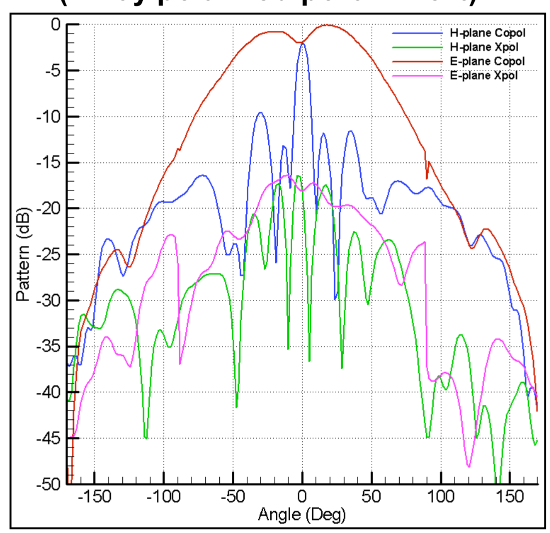
Measured Pattern: Lower-Patch (Cross-array polarized port : V-Port)



Measured Pattern: Lower-Patch (Array polarized port: H-Port)



Measured Pattern: Upper-Patch (Cross-array polarized port: V-Port)

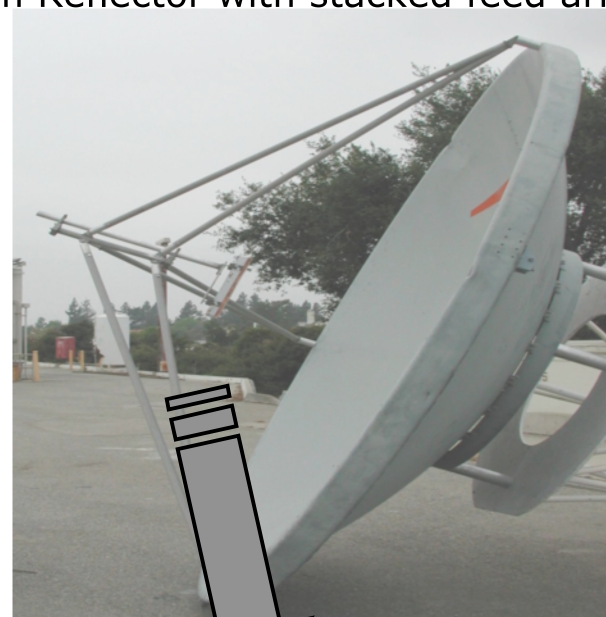


Measured Pattern: Upper-Patch (Array polarized port: H-Port)

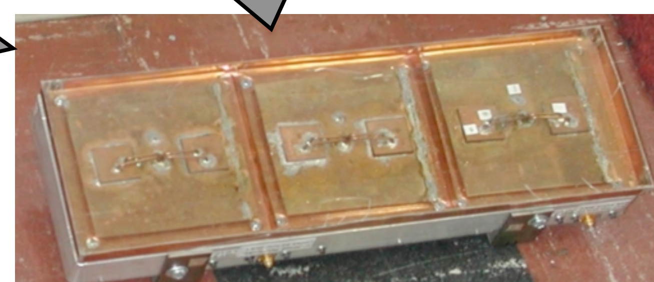
Integration of the Scaled Frequency Feed with 3.65m reflector

3.65m Reflector at JPL

3.65m Reflector with stacked feed array at focus

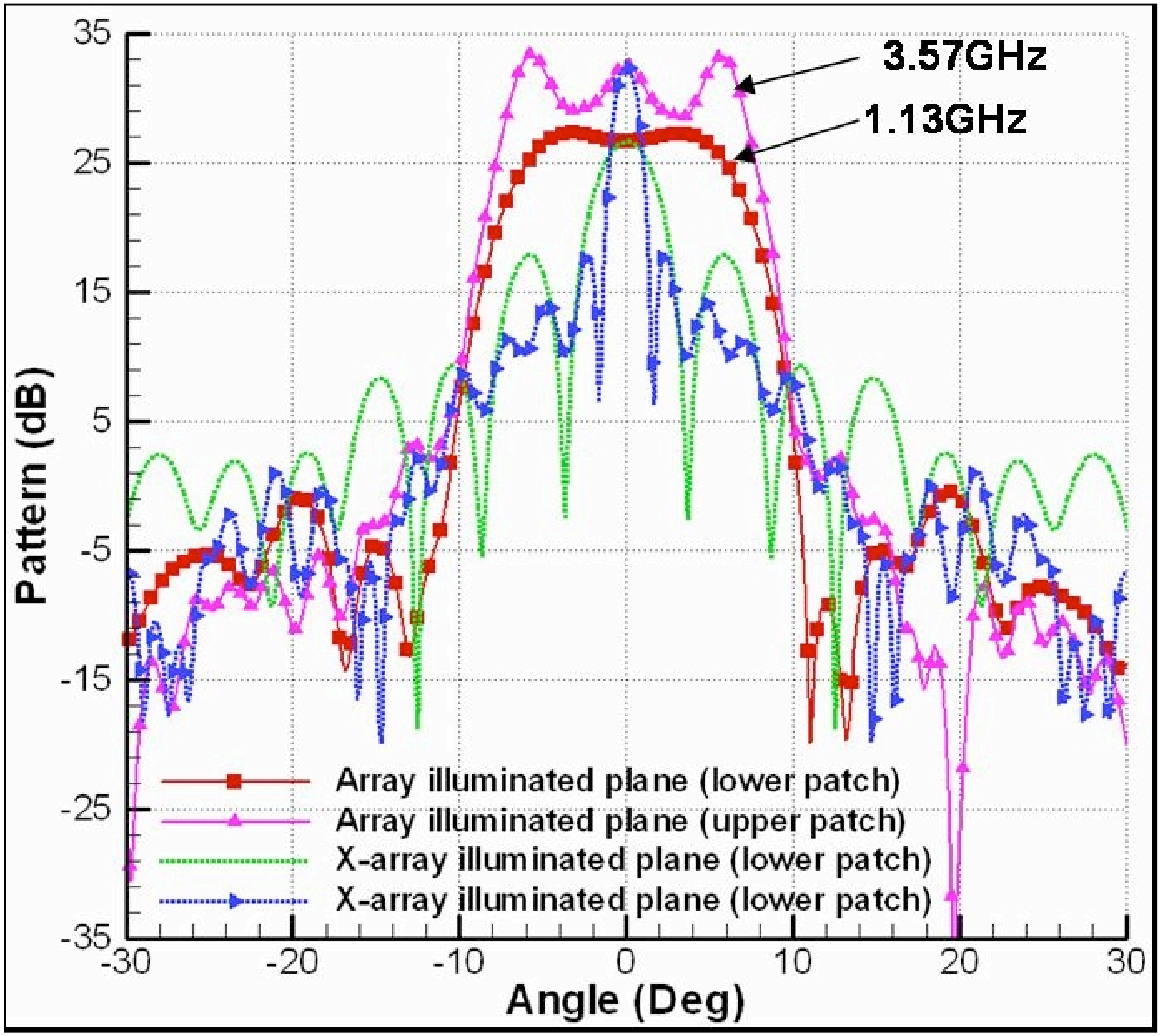


Stacked–feed array at focus

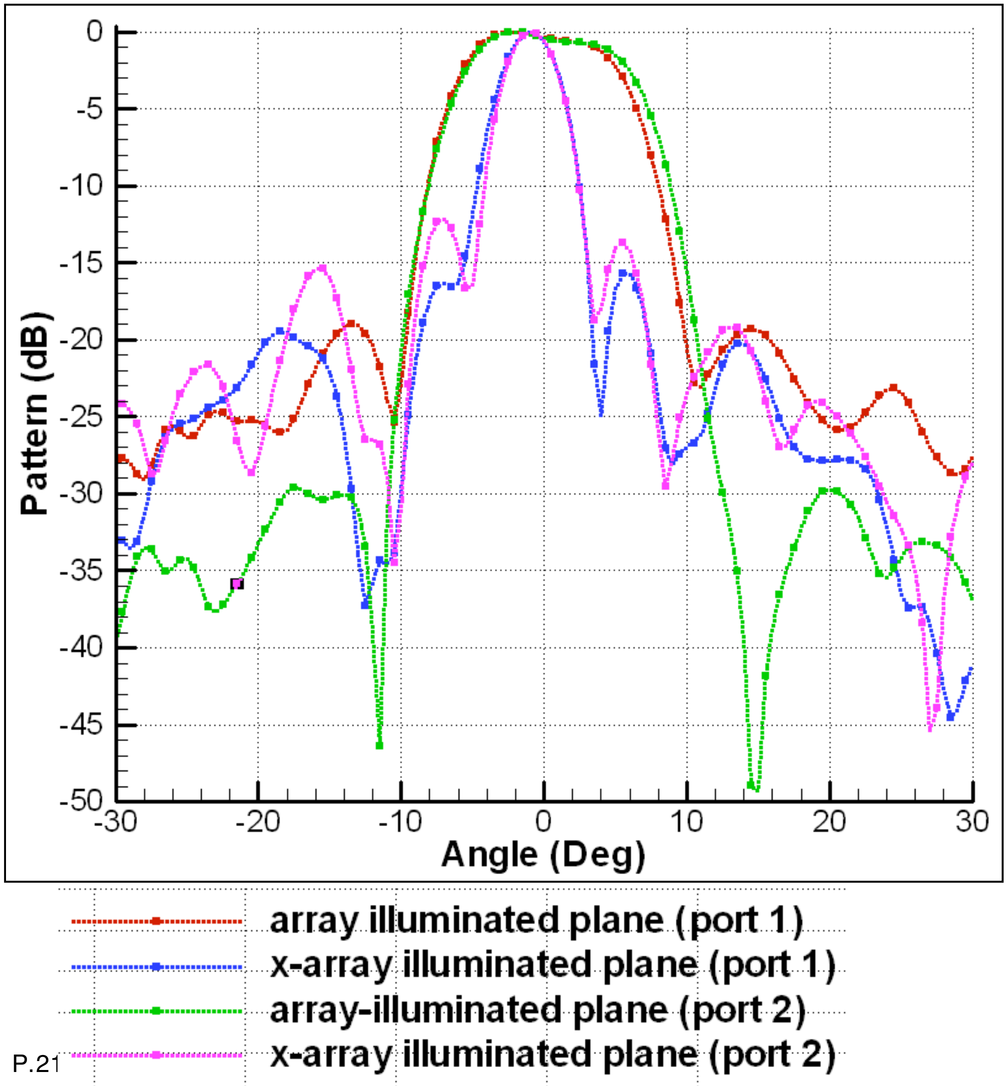


Dual-frequency dual-polarized stacked-feed array

Simulated far-field radiation pattern for the 3.65m reflector (with the stacked patch array at focus)

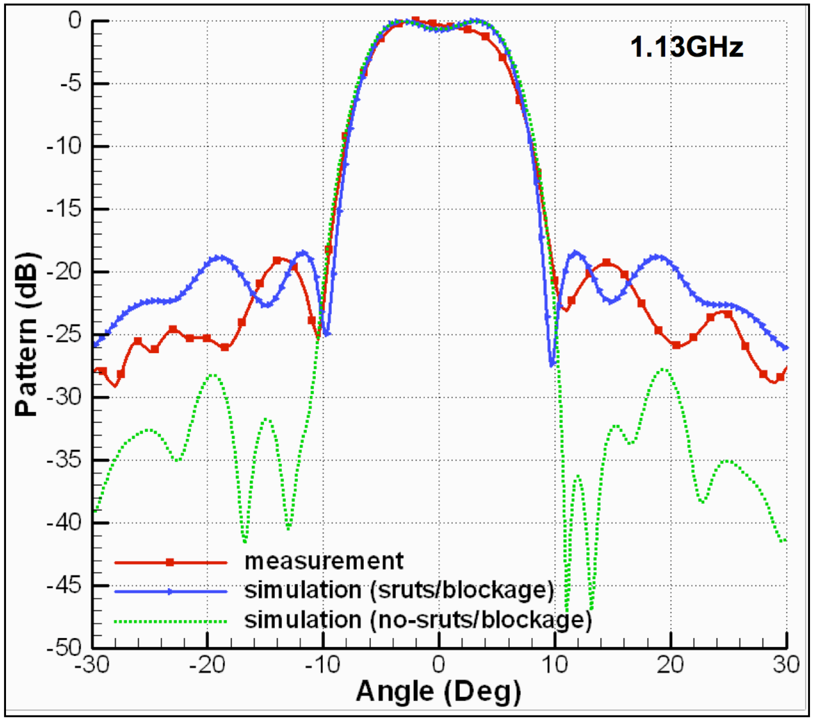


Comparison of Measured Results from 3.65m Reflector for both polarizations (Lower frequency : 1.13GHz)

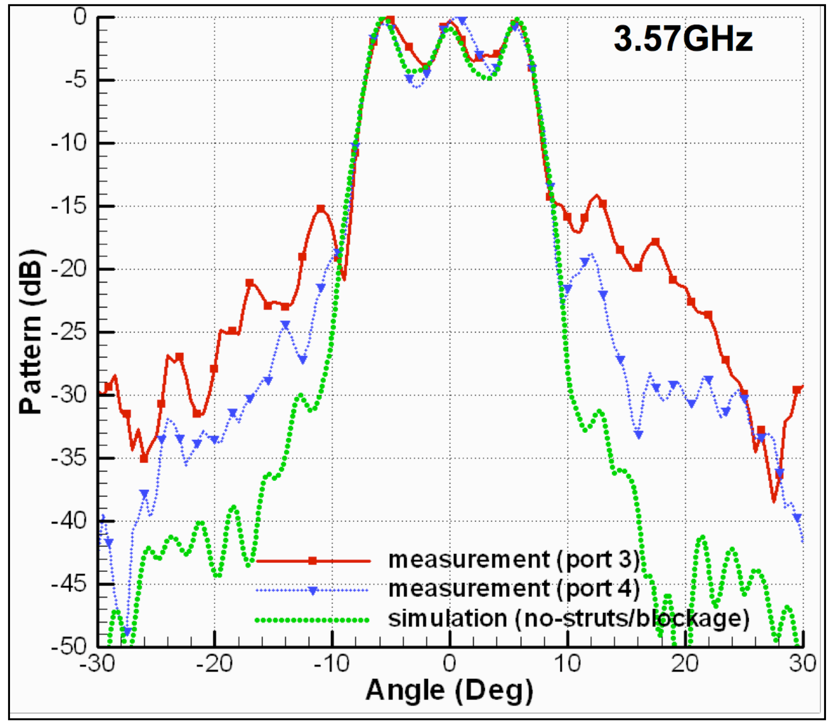


- A slight shift in pattern from boresight was seen due to pointing error during mounting.
- The two orthogonal polarizations have similar beamwidths in both planes.

Comparison of Simulation and Measured Results from 3.65m Reflector



Comparison between measured and simulated E-plane pattern of reflector at 1.13GHz with excitation at lower patch cross-array polarized port of the stacked patch array.



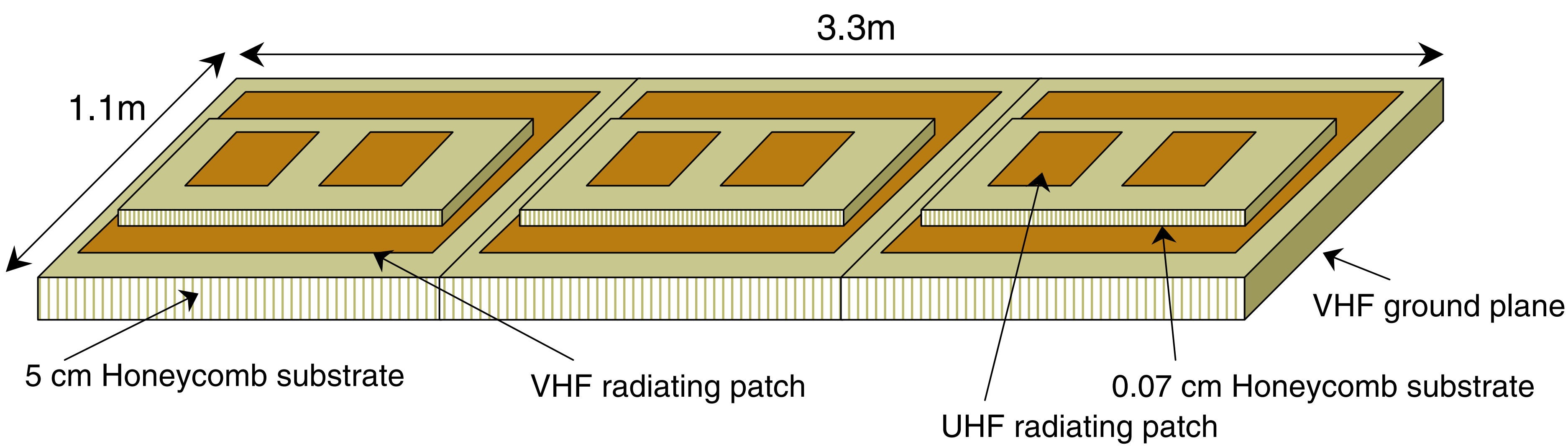
A comparison between E-plane pattern of the reflector at 3.57GHz with simulation (without feed blockage and strut effect) and measured pattern with excitation at the port 3 (V- port) and port 4 (H-port).

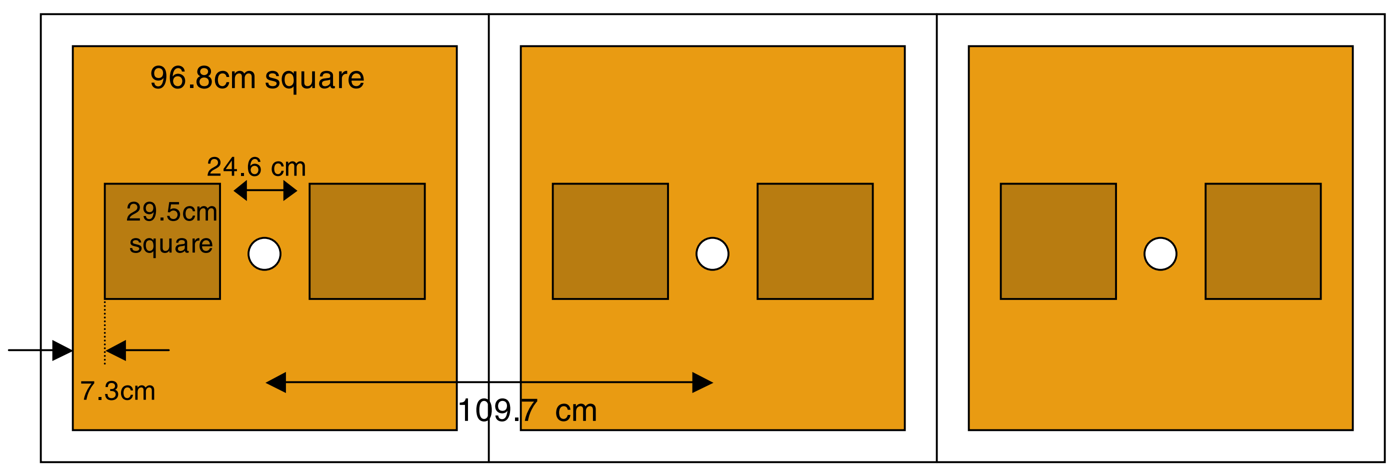
Scaled Feed Summary and Observations

- **Dual-stacked patch element and array configuration design has been completed**
  - The simulated radiation pattern for the lower patch shows a high back-radiation due to a small ground plane (twice the substrate thickness is required to account for fringing fields). Metallic side-walls improved the back-radiation levels by ~8dB. It also helps shaping the beam in main-beam direction.
  - Metallic side-walls inserted in middle of patches also helped in reducing the mutual coupling between the radiating edges of the patches in the array (while feeding in the array plane).
  - Simulations and measurements from the reflector produce similar wide pulse-like beamwidth for the two operating frequencies in one plane and a narrow beam in the other plane.
  - The beamwidths for the orthogonal polarizations are as designed;

Full-Scale Antenna Feed

Dual-band Stacked Patch Configuration

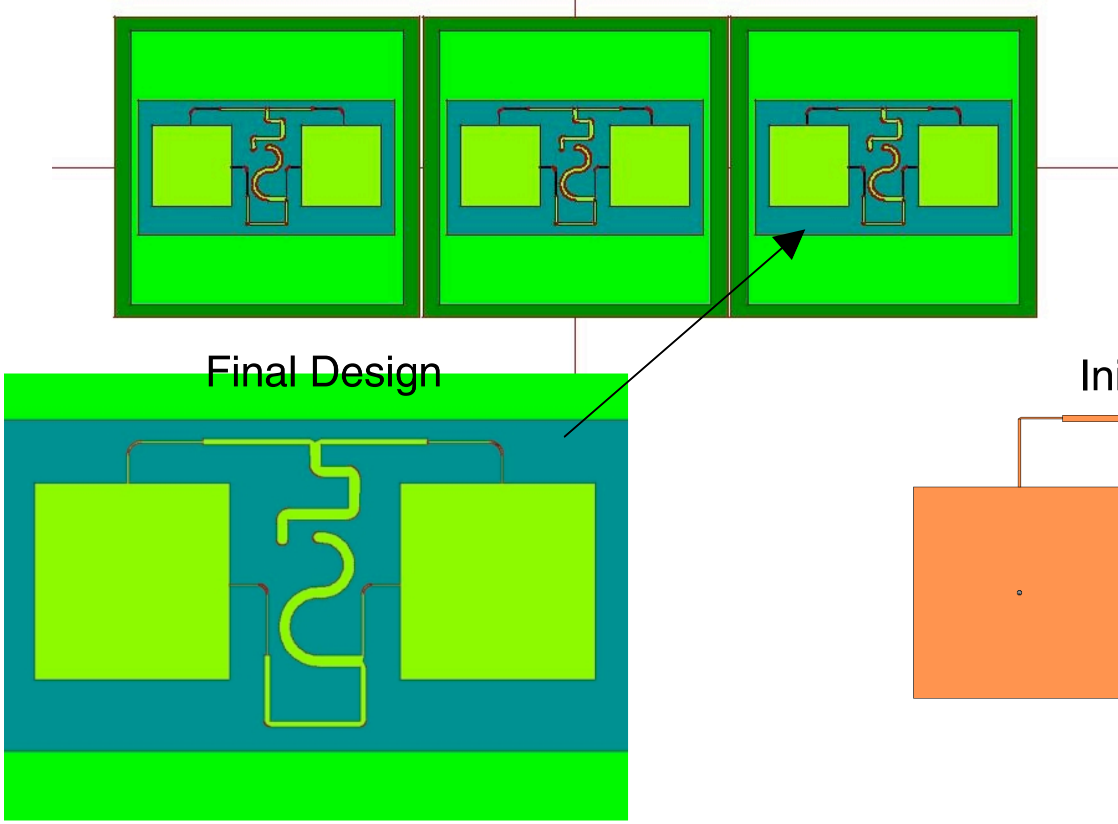




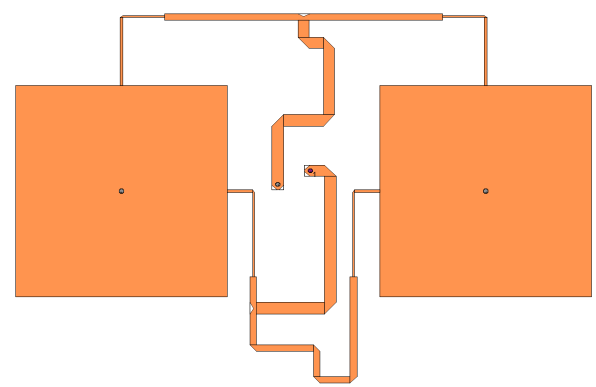
Full-Scale Antenna Feed

Design considerations

- Dimensions were iterated using estimates of the honeycomb dielectric constant for each frequency
- Corporate feed network was designed to eliminate sharp edges, which could be causing radiation losses. The design also avoids parallel lines in proximity of each other which could cause coupling



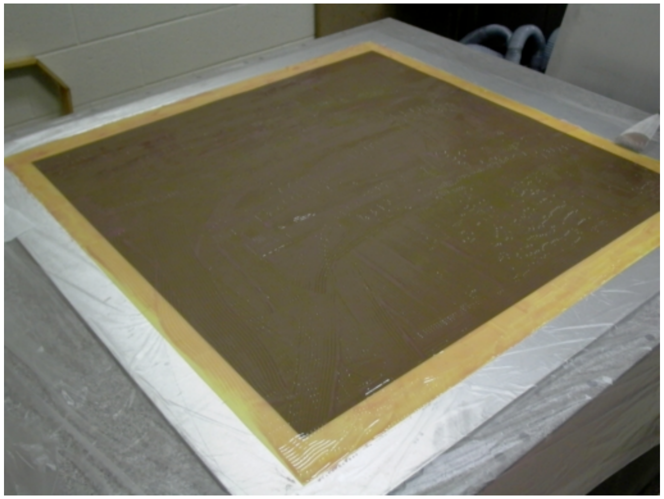
Initial Design

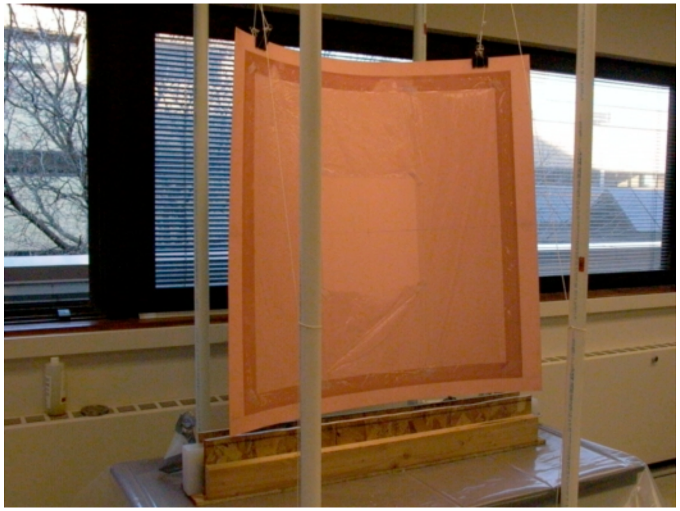


Full-Scale Antenna Feed

Element Fabrication

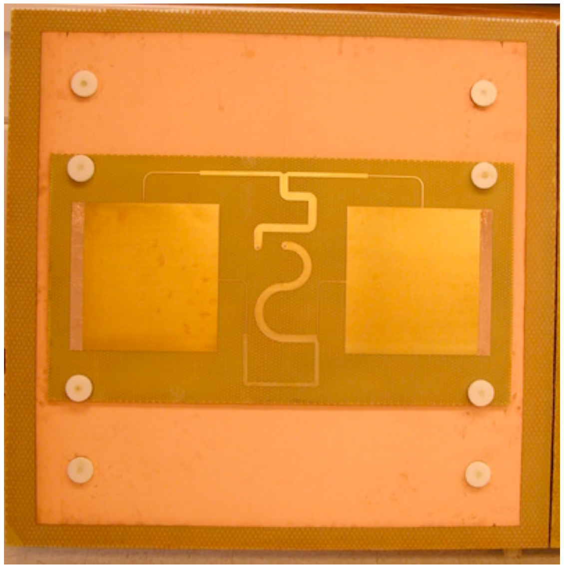
- The VHF and UHF radiating patches and ground planes were built from 10mil copper clad G10 sheets. These were special order items for VHF due to their size.
- The ground planes were first glued to the honeycomb substrate and weighed down on an ultra-flat optical table. A comb was used for uniform application of glue.
- An in-house etching bath was built to etch the VHF patches to the right size.
- The UHF elements were sent out for etching
- The patches were glued to the honeycomb with the same technique as above
- A nearly circular shape was then cut out from the center to run the feed lines for the UHF elements to be stacked on top





Element Fabrication, con't.

- Antenna materials
  - HRH-10 fiber/resin Honeycomb (Hexcel)
    - 0.7cm and 5cm thick
  - EA 9309 two part epoxy (Hysol)
  - G10/FR4 (Polyclad Laminates)
    - Single side 1oz copper clad
    - 42"x48" (VHF)
  - TNC connectors



3-Way Power Dividers

- To feed the three subarray elements uniformly, a three-way Wilkinson power divider was designed for each frequency and polarization.
- Various design considerations (compactness, low loss, thermal properties, lead time, ease of fabrication) led to the selection of TMM6 material for power divider substrates.
- Fabrication done off-site
- Design requirements were given as follows:

	VHF	UHF
Center Frequency	137.5 MHz	435 MHz
Isolation	15 dB	15 dB
Phase Variation	< 3^o	< 3^o
Amplitude Variation	< 0.1 dB	< 0.1 dB
Power Handling	200 W average	200 W average

Power Divider Performance Summary

- All ports are well matched
- All phases are linear, with small spread
- Isolation between ports exceeds requirements
- Equal power division is achieved within tolerance

	VHF1 @ 137.5 MHz	UHF1 @ 435 MHz
S11	-20.2 dB	< -16.2
Power Division Port 2,3,4	-4.90, -4.90, -4.96 dB	-4.98, -5.01, -4.90 dB
S22, S33, S44	< -19.3 dB	< -16.9 dB
Port 2,3,4 Isolation	< -23.1 dB	< -18.5 dB
Phase spread	0.6°	2°

Cables

- There are 12 cables that feed the antenna elements from the power dividers: 2 frequencies, 3 subarray elements, 2 polarizations
- Each cable was measured separately for amplitude loss and phase variations, since this could potentially impact the performance of the array.

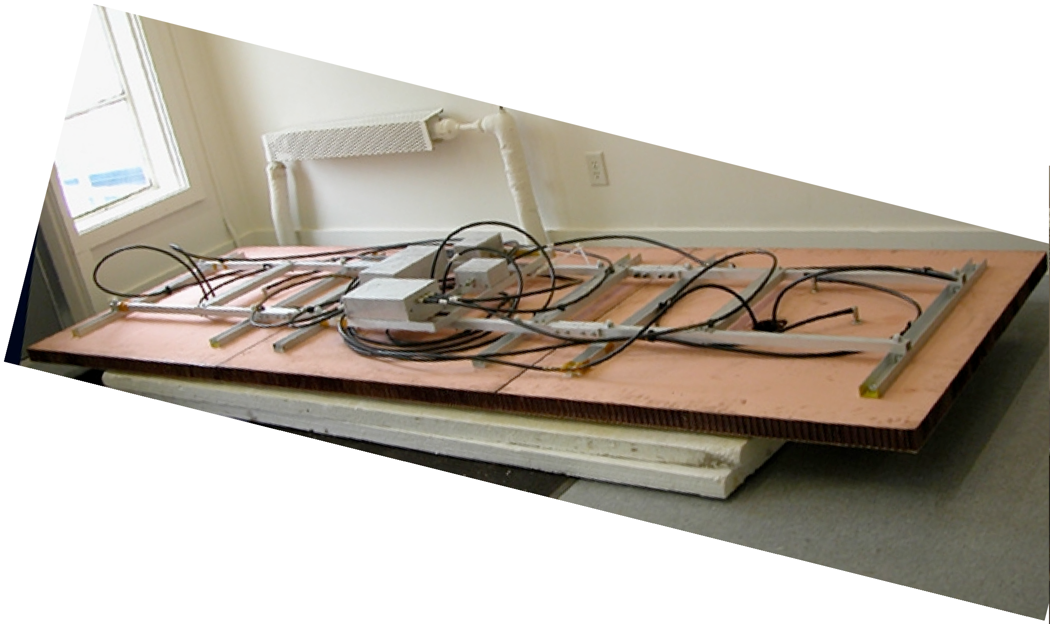
	137.5 MHz	435 MHz
Reflection (S11)	< -35 dB	< -30 dB
Insertion Loss*	-0.14 dB	-0.28 dB
Power Loss (2.5 m)*	3.2%	6.3%
Phase spread	~1.1°	~3°

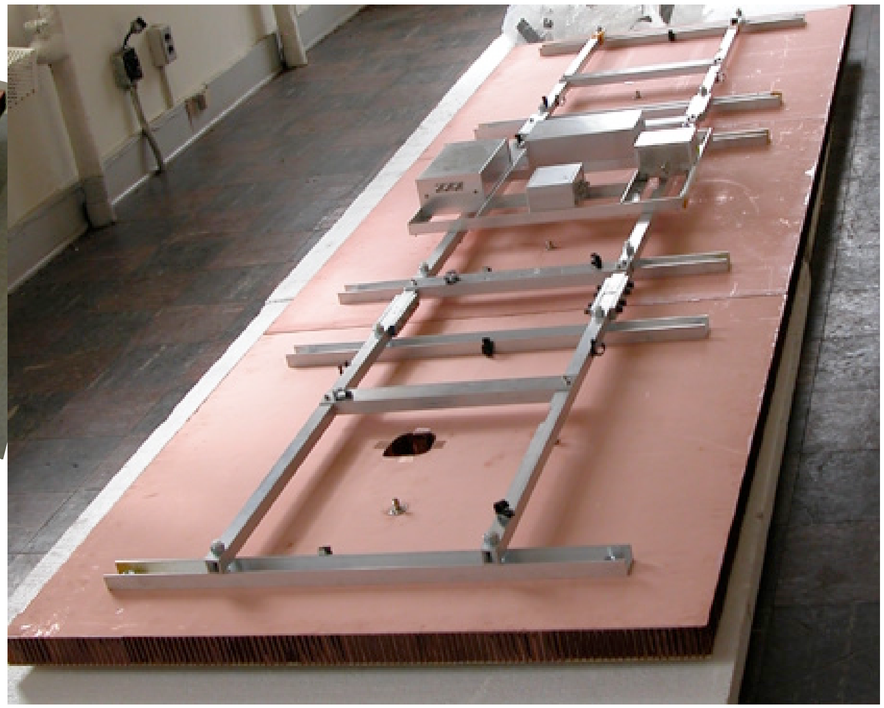
* average of least squares fit

Full-Scale Antenna Feed

The Completed Feed Array

- Aluminum structure was built in-house, and used to attach the array elements with careful attention to fastener locations on both VHF and UHF panels.
- Power dividers were mounted on their own assembly and attached to the main structure





Completed Array weight: 39.8 kg

Full-Scale Antenna Feed

Pattern Measurements at the Willow Run Outdoor Range

- **Pattern measurements were done at the outdoor antenna range**
  - The150-ft range has a ground reflection design, with center of test antenna located at 6’ above ground
  - The range has a 360-degree turntable with 1-degree resolution
  - The transmit antenna is a wide-band log periodic
  - A wooden stand was built to hold the antenna
  - Full gain measurements were performed with standard gains (dipoles)

Pattern Measurements at the Willow Run Outdoor Range

- Pattern and gain were measured for the two principal planes and for the entire 360-degree view angle range

Pattern Measurements at the Willow Run Outdoor Range

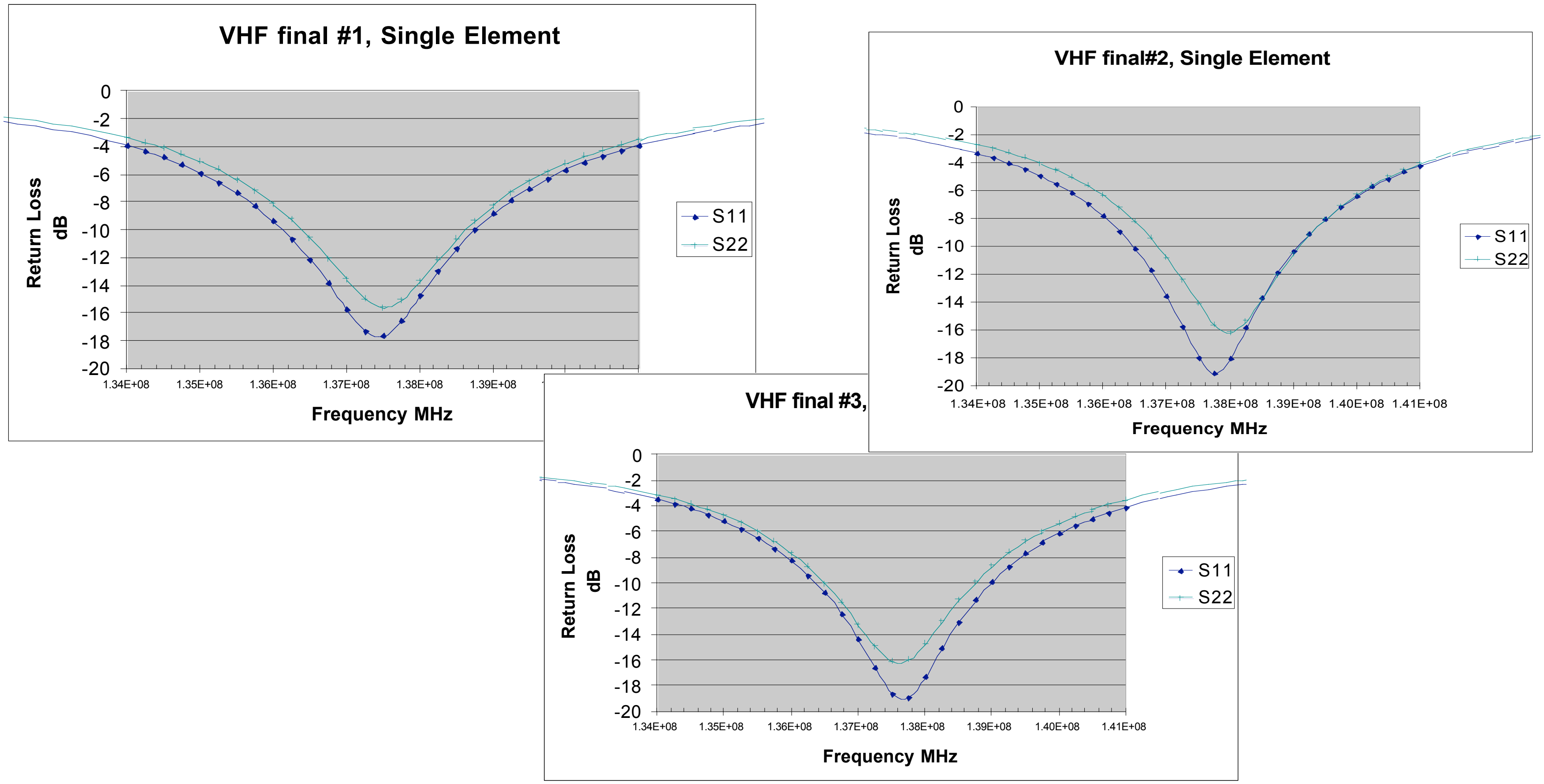
- Pattern and gain were measured for the two principal planes and for the entire 360-degree view angle range
- Note center of array is ~6ft above ground

VHF Array Measurements with Walls

- The VHF array manifests large back lobes for both polarizations
- To remedy the problem, copper walls were added all around
  - 20cm from the bottom of ground plane, i.e., 15cm from the patch plane
  - Fastened to ground plane via copper tape

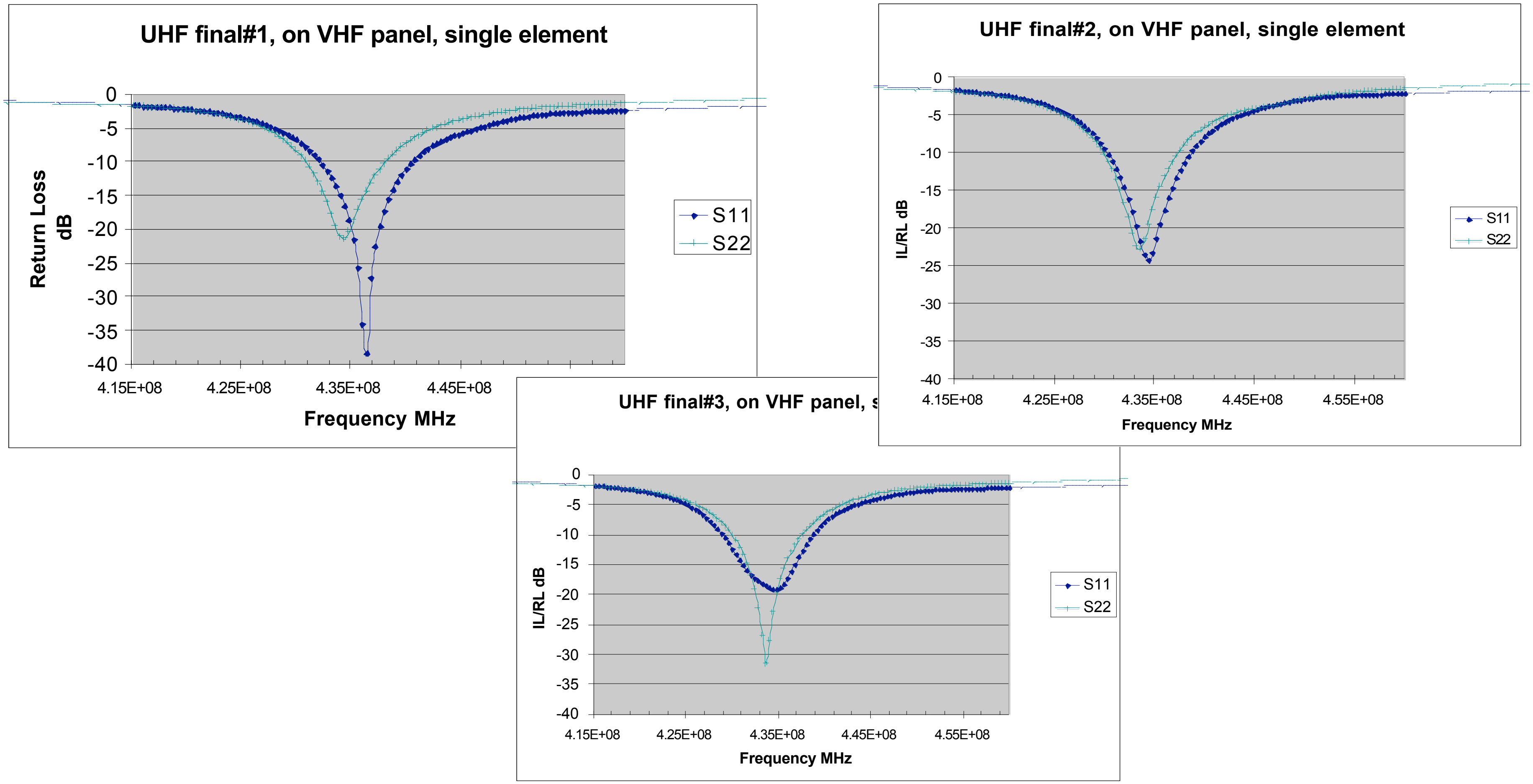
Full-Scale Antenna Feed

VHF Subarray Measured Return Loss



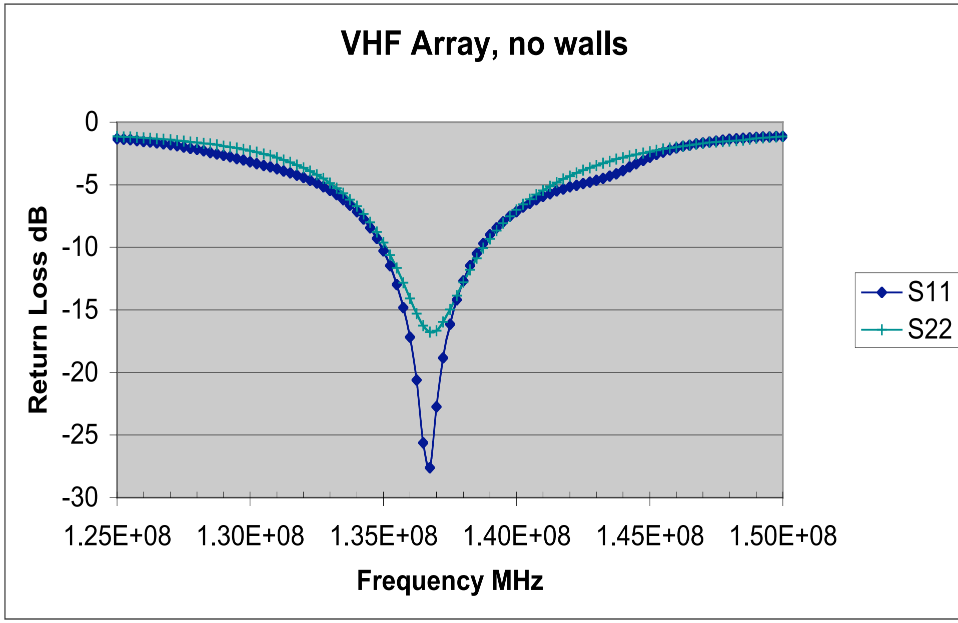
- Performance characteristics:
  - Both polarizations are tuned quite well at 137.5 MHz. Note that Panel #3 has the best return loss and therefore was used as the center element of the array to effectively produce a tapered beam.

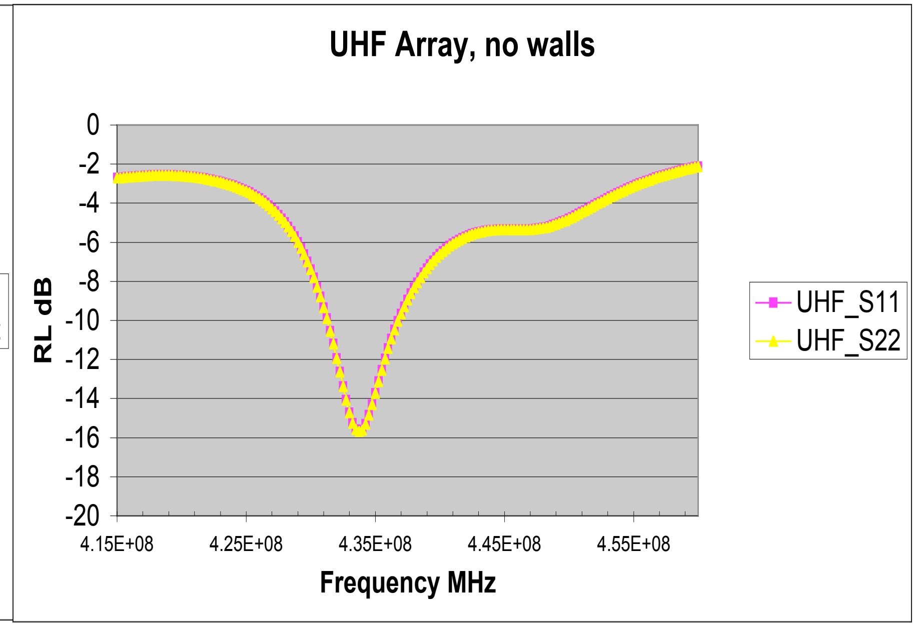
UHF Subarray Measured Return Loss



- Performance characteristics:
  - All panels are tuned quite well at 435 MHz. Panel #1 V and H pols are somewhat offset, but still at 435 MHz they are both matched very well

VHF and UHF Arrays Measured Return Loss





- Performance characteristics:
  - Both bands are very well tuned at the desired center frequency
  - V and H polarizations (S11 and S22) are quite well co-located
  - The VHF cross-array port (port 2) has a larger reflection coefficient and so we expect lower gain at this channel

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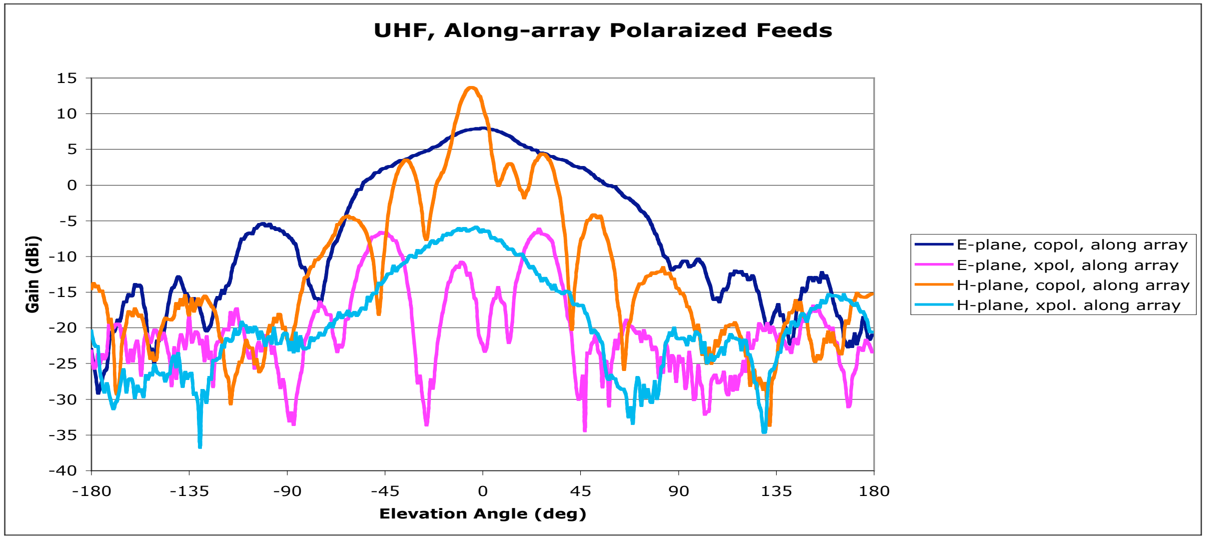
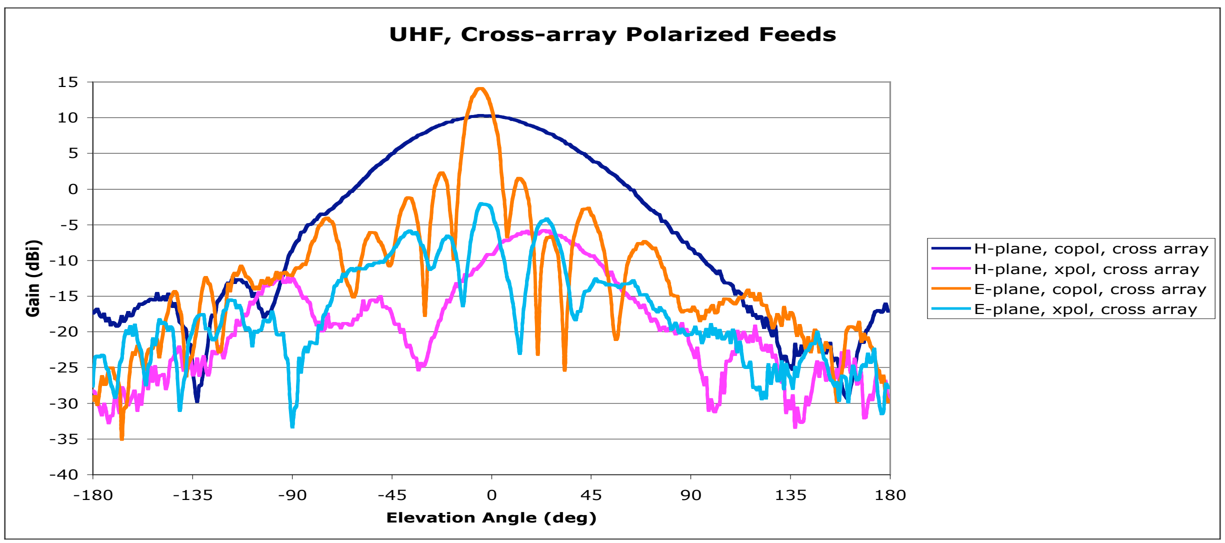
Full-Scale Antenna Feed

UHF Array Measured Patterns



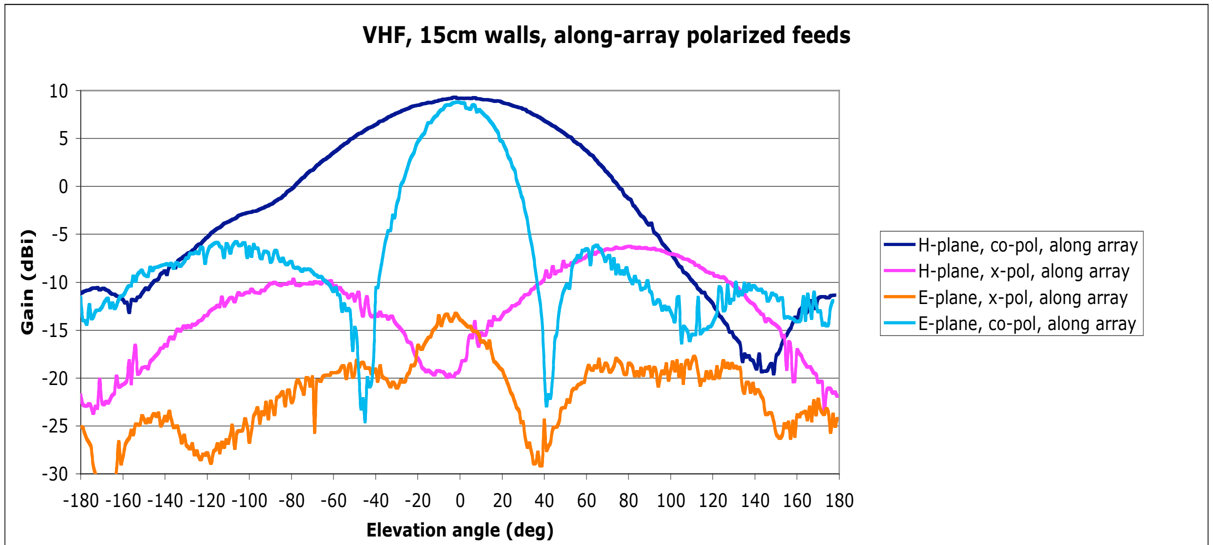


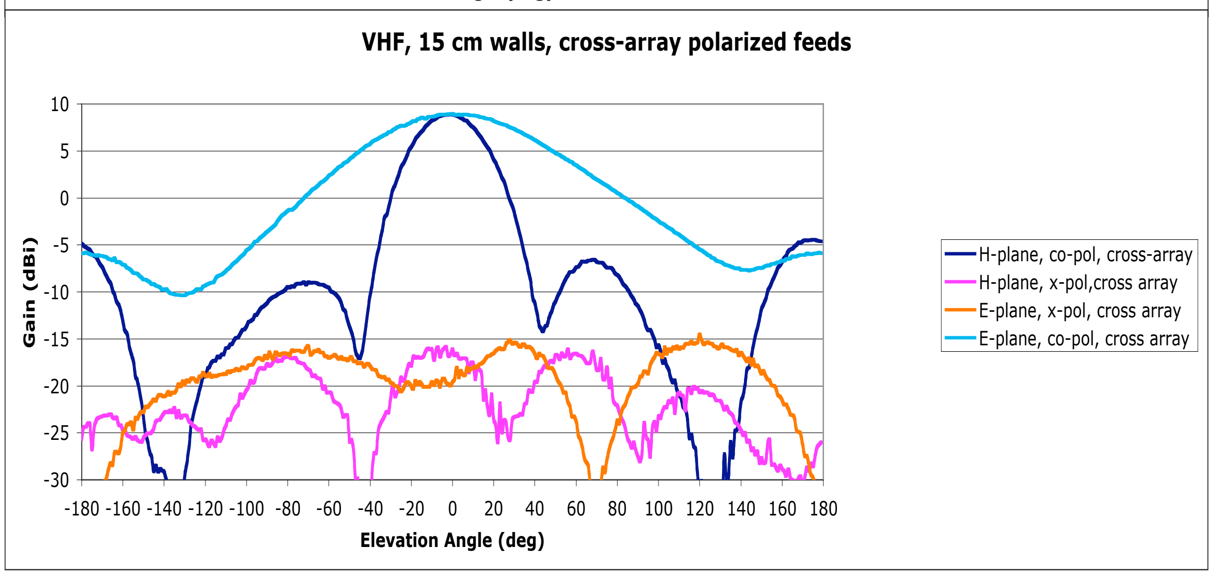
Performance characteristics:

- beamwidths:
  - H-plane cross-array: 65 deg
  - E-plane cross-array: 10 deg
  - H-plane along-array: 12 deg
  - E-plane along-array: 62 deg
- Gain:
  - H-plane cross-array: 10.0 dBi
  - E-plane cross-array: 13.9 dBi
  - H-plane along-array: 13.6 dBi
  - E-plane along-array: 7.7 dBi
- Backlobes are quite small, due to the large effective ground plane
- Cross-pol patterns are generally at least 15 dB below the co-pol pattern in the main lobe.

Full-Scale Antenna Feed

VHF Array Measured Patterns with Walls





Performance characteristics:

- beamwidths:
  - H-plane cross-array: 26 deg
  - E-plane cross-array: 79 deg
  - H-plane along-array:71 deg
  - E-plane along-array: 27 deg
- Backlobes have been reduced significantly, and very close to the amount predicted by simulations
- The beams have a much better definition. Nulls are filled.
- Cross-pol patterns are generally at least 20 dB below the co-pol pattern in the main lobe.

Full-Scale Antenna Feed

Gain Assessment

	VHF gain (dB) (measured/simulated)	UHF gain (dB) (measured/simulated)
V-port E-plane	8.9/10.2	8.0/13.2
V-port H-plane	8.9/10.2	11.1/13.2
H-port E-plane	8.8/10.1	11.2/12.9
H-port H-plane	9.2/10.1	10.2/12.9

Sources of Loss

	VHF	UHF
Reflection (S11)	2-5%	3-4%
Power divider insertion loss (S21)	1-2%	1-2%
Cable losses	3-4%	4-6%
Calibration and modeling	5-10% (estimated)	15-20% (estimated)
Antenna panel losses	Remainder	Remainder

Summary and Observations

- The full-size VHF/UHF antenna feed array prototype was successfully built and tested
- This task demonstrated the validity of the design and feasibility of constructing such a feed system for a future spaceborne radar that has a 30-m mesh reflector antenna
- The TRL for this feed systems was advanced to at least 5
  - More detailed assessment (perhaps leading to TRL 6) depends on how systems and subsystems are classified
- To further mature this feed system, the following need to be addressed:
  - Lighter-weight back support structure
  - Light-weight retractable sidewalls to reduce backlobe
  - Housing for cables and power dividers on the back of array
  - Design improvements to achieve more symmetric sidelobes and nulls

30m Mesh Reflector Mechanical Design
Spacecraft/Systems Design

Task Summary

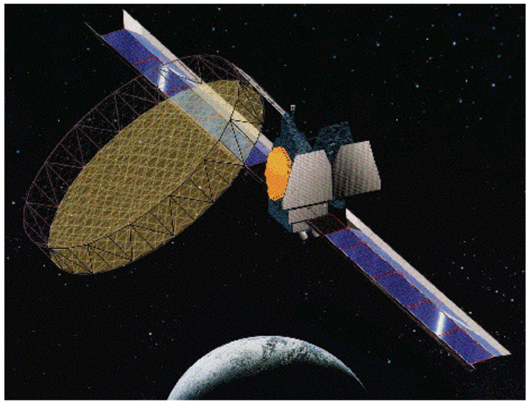
Top-Level Architectural Study
- Reflector Tradeoff
- Reflector and System Rough Sizing
- Mesh Evaluation

Spacecraft Systems Accommodation Study
- MOSS Mission Requirements
- Spacecraft Payload & Subsystems Trades
- Launch Vehicle Considerations
- Deployment Kinematics

Deployable Antenna Systems Design
- Deployment Configuration Tradeoff results
- Detailed Antenna System Layout and Mass
- Detailed Design Refinement with Final Mass Estimate
- Deployment Sequence graphicsD
- 1:30 Scale model

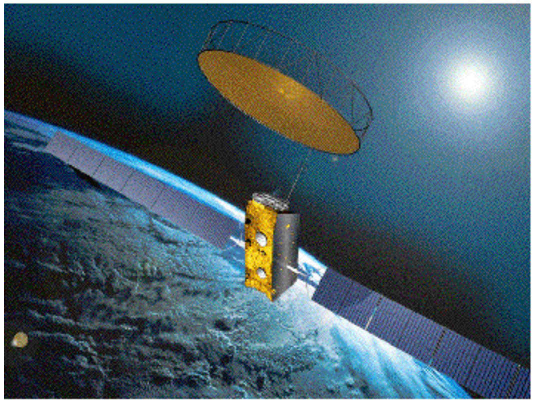
Heritage Parabolic Reflectors for Radar

- Structure is a flight proven cable-deployed perimeter truss

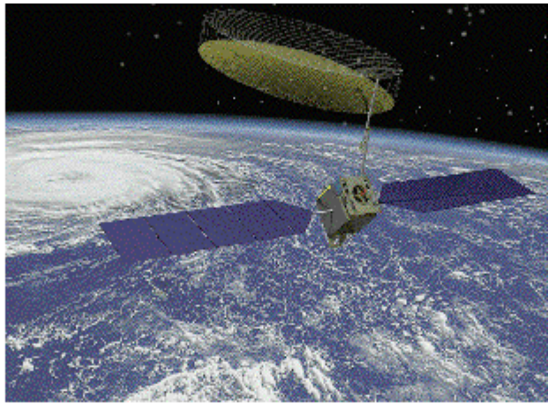


THURAYA/GEM
- *4 - 12.25-m flight reflectors*
- *13.5 Hz stowed frequency*
- *0.63 Hz deployed frequency*
- *112 kg subsystem mass*
  - *56 kg reflector*

Two successful on-orbit deployments
- *D1 launched 10/2000*
- *D2 launched 6/2003*



INMARSAT 4
- *3 - 9-m aperture reflectors*
- *35 Hz stowed frequency*
- *0.15 Hz deployed frequency*
- *92 kg subsystem mass*
  - *35 kg reflector*
- *First launch late 2004*



MBSAT
- *Single 12-m aperture reflector*
- *35 Hz stowed frequency*
- *0.37 Hz deployed frequency*
- *110 kg subsystem mass*
  - *47 kg reflector*
- *Launch 1st qtr 2004*

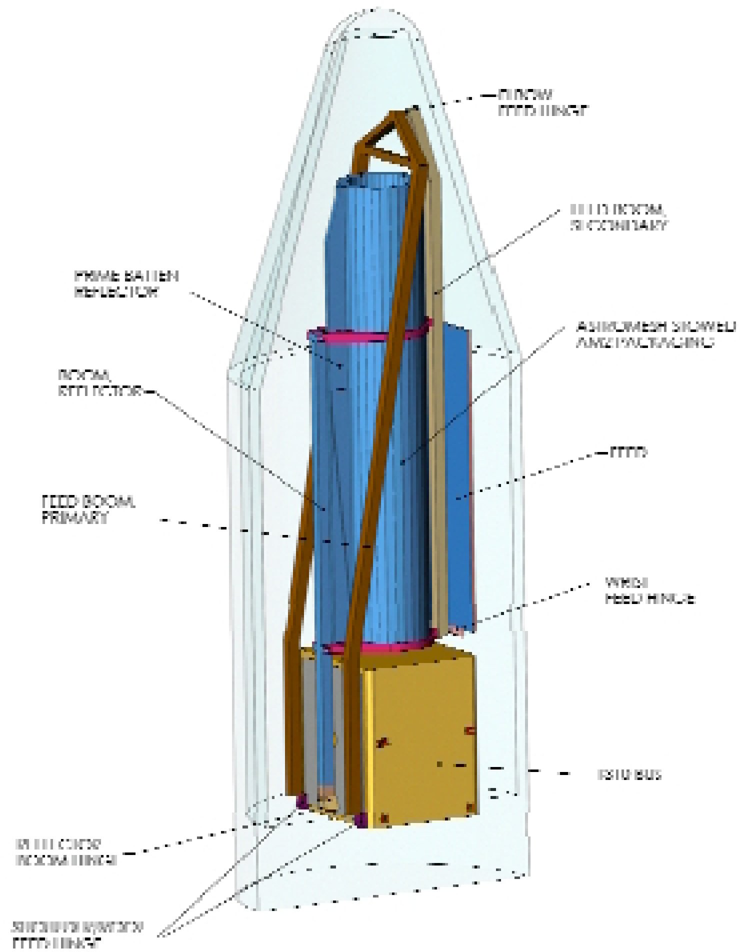
Five Units On-Orbit by 2005

Summary Findings

- Minimum stowed natural frequency (from FEM): 14.1 Hz
- Minimum deployed natural frequency (from FEM): 0.30 Hz
- Thermal distortion of 30 m x 11 m reflector surface:
  – 0.038 in (.097 cm) rms
- Reflector subsystem mass: 495 kg

Deployable Antenna Systems Design (ASTRO)

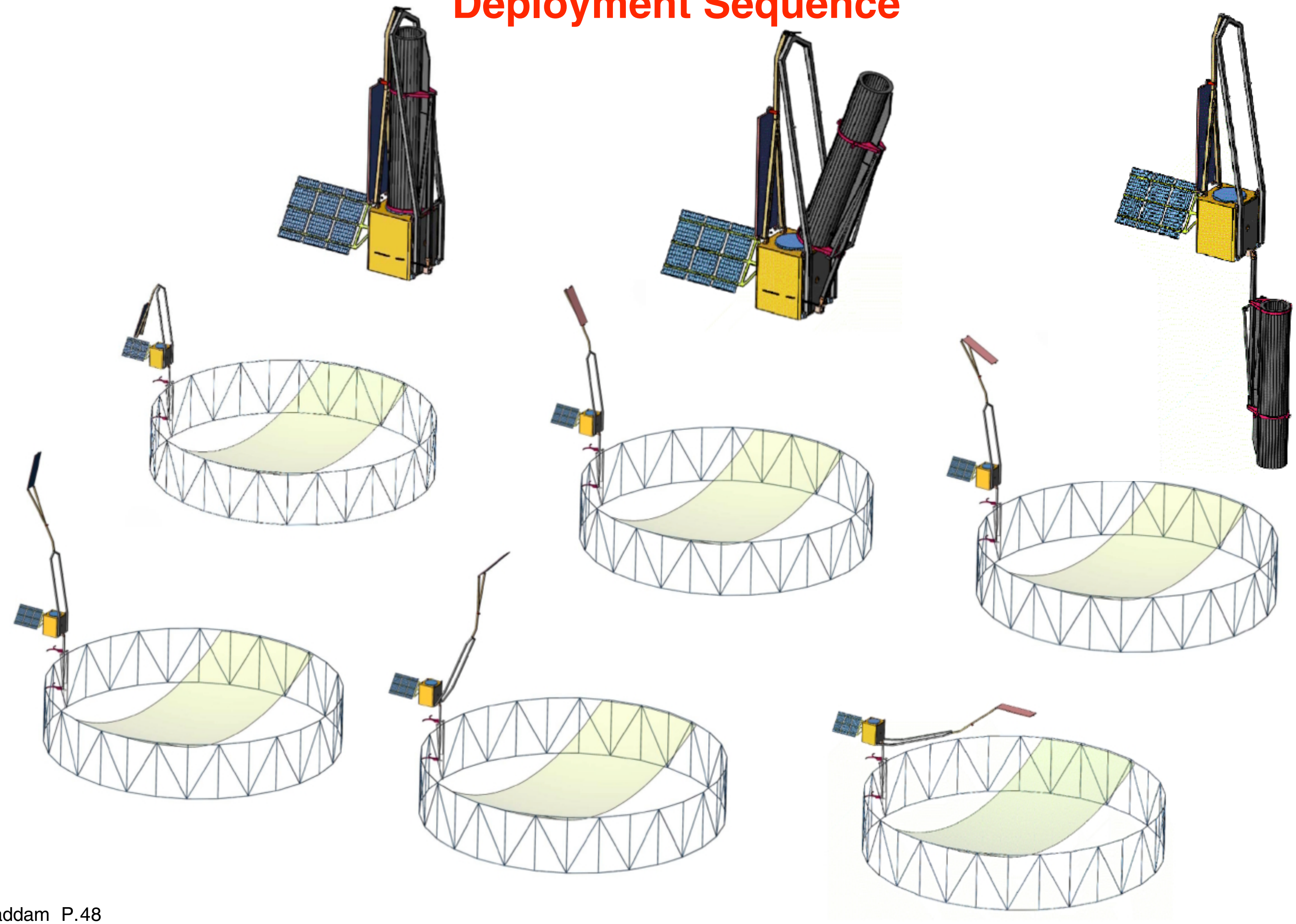
- Deployment Configuration Tradeoff Results
  - Numerous stowed design layouts were generated resulting in the selected point-design shown
  - The point design has minimum complexity:
    - Fewest deployment hinge lines, only one hinge between reflector/bus
    - Simplest kinematics
    - Short, dual reflector boom offers potential for highest system stiffness stowed and deployed
    - Most compact and lowest mass configuration found



MOSS

30-m Mesh Reflector

Deployment Sequence



Status: 30-m Mesh Reflector

Scale Model
Currently on Display at JPL

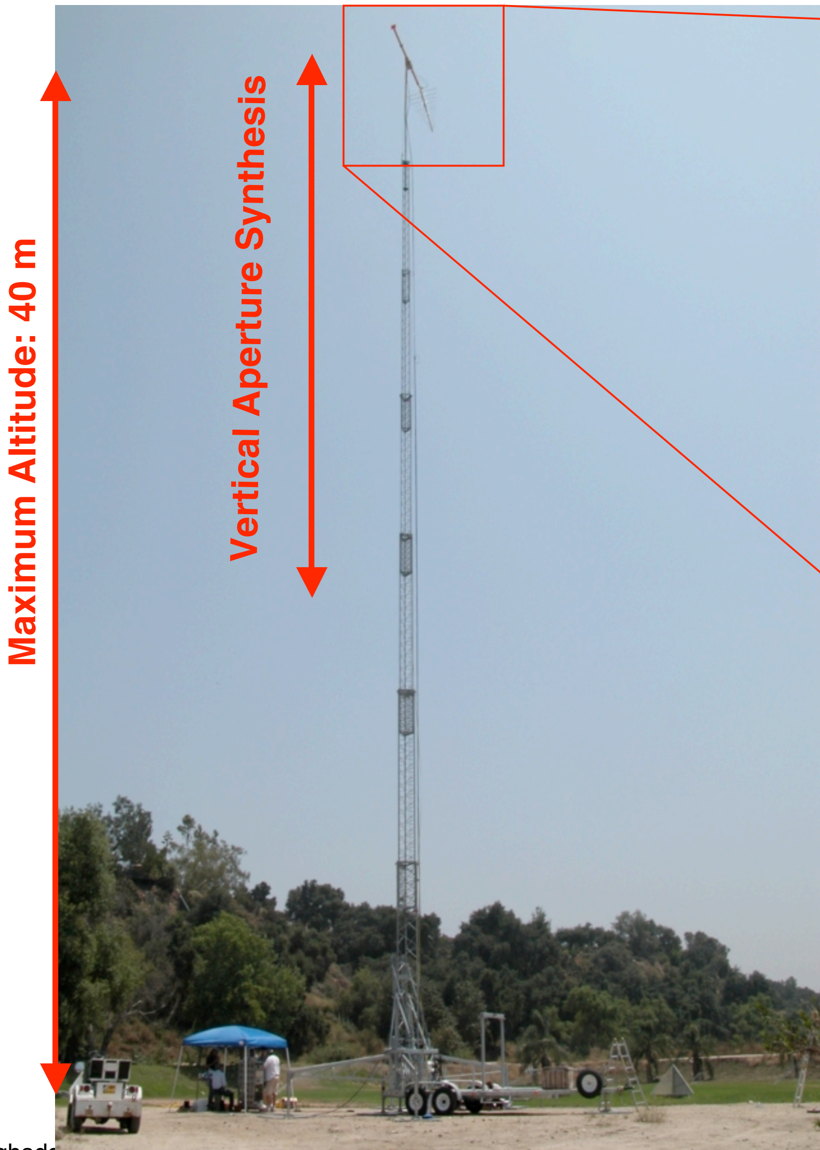
Tower Radar Experiments, Science Algorithms, and Radar Processor

Motivation

- Proof-of-Concept for proposed measurement scenario and science products
  - demonstrate frequency-dependent radar penetration effectiveness for soil moisture
- Prototype science data set parameters:
  - VHF (137 MHz), UHF (435 MHz), and L-band (1000 MHz)
  - Polarimetric
  - Test sites deployed:
    - Arid/semiarid (Arizona, Fall 2003)
    - Temperate forest (Oregon, Winter 2003 & Spring 2004)
  - Extensive "ground-truth" with deep *in-situ* probes

MOSS

Tower Radar



- Pulsed radar: pulse length ~50nsec (~20MHz bandwidth)
- Dual-pol coherent radar for frequencies from VHF (137 MHz) to UHF (425 MHz) to L-Band (1GHz)
- Antenna beam-width ~70 deg => aperture synthesis is required to narrow footprint and incidence angles
- Aperture synthesis in vertical direction only

The Arizona Experiments

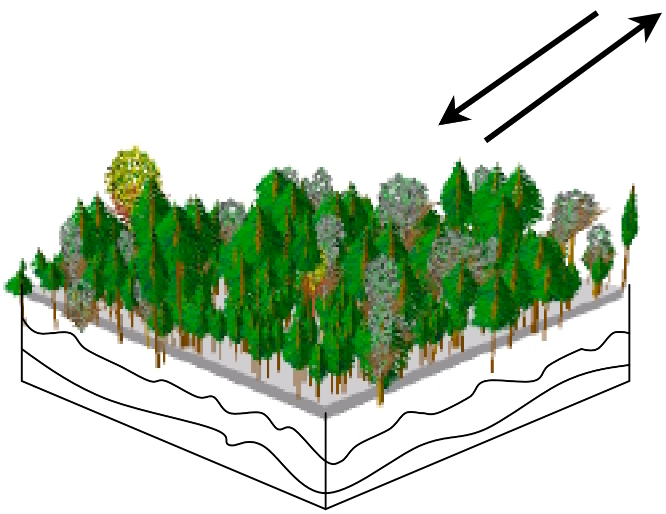
- Location: Lucky Hills, Arizona (Walnut Gulch drainage)
- Collaboration: US Department of Agriculture (Tucson/Tombstone)
- Initial data collect (9/21): dry ground
- Data collection every day for 4 days - included post-rain data
- Additional data: contemporaneous soil moisture measurements (5, 10, 15 cm depths). Additional TDR data at depth from a nearby calibration trench

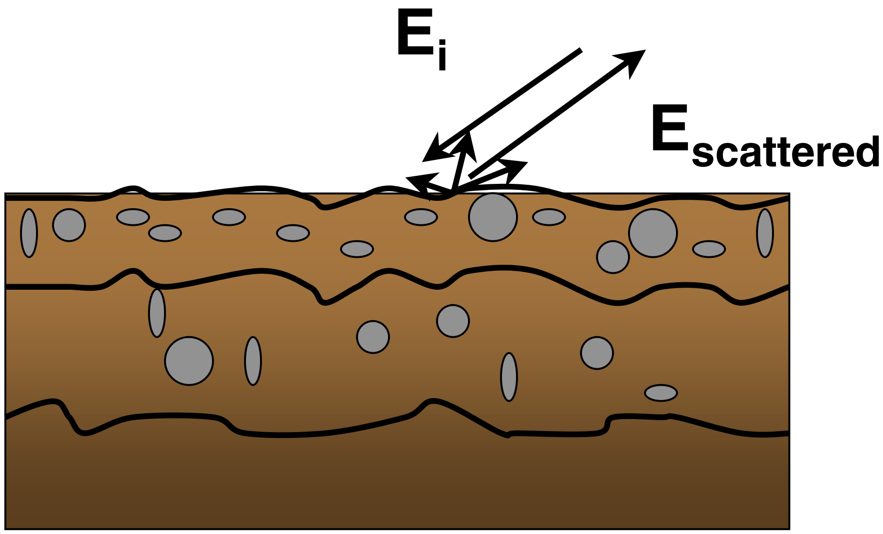
Oregon Experiments

- Hinterland Llama Ranch near Sisters, Oregon, December 2003
- Deep soil moisture probes installed by Co-I at Oregon State University

Scattering Model

- This is a layered medium problem, where direction of incidence and scattering observation are the same
  - Multiple rough interfaces to model soil layers
    - Interfaces could be due to multiple soil types, bedrock, or permafrost
  - Rocks and other inclusions might be present
    - Initially assume that at UHF and VHF these contributions are small
  - Vegetation might be present



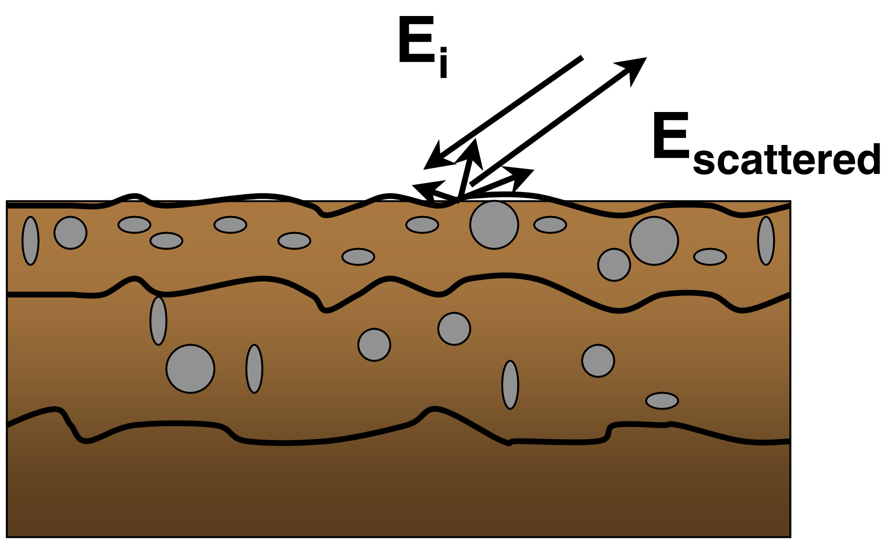


Modeled Subsurface Cross Section

Soil Moisture Estimation Algorithm

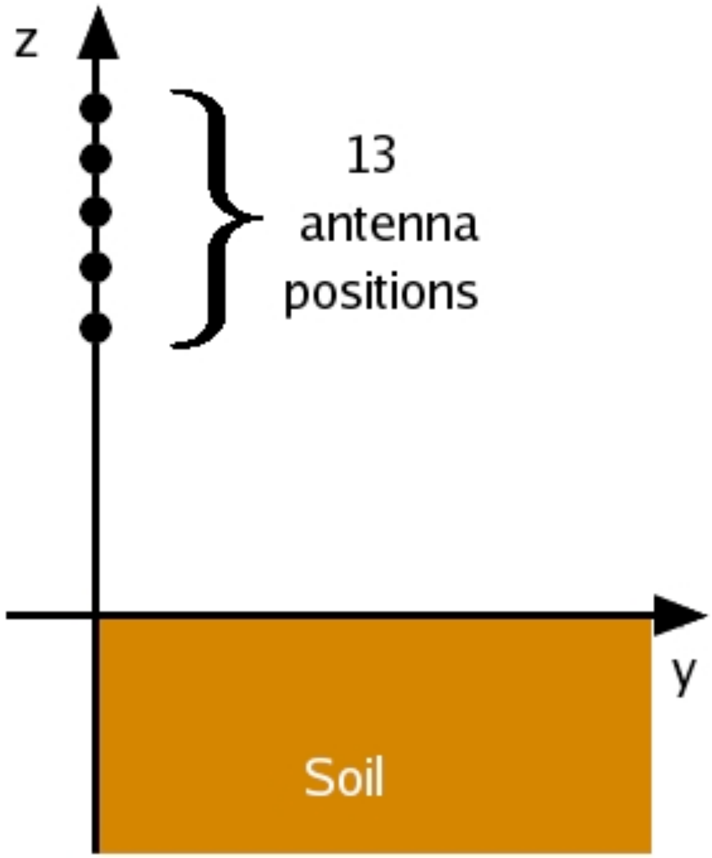
- Step 1
  - Need a "good" **forward scattering model** that predicts radar backscatter from known surface and subsurface soil parameters
  - Model needs to strike a balance between accuracy and reasonable computation time

- Step 2
  - Solve the inverse problem
  - Almost always have to resort to an **optimization technique**, regardless of numerical or analytical forward model
  - Direct inversion is not possible due to nonlinearity of the problem in general



Modeled Subsurface Cross Section

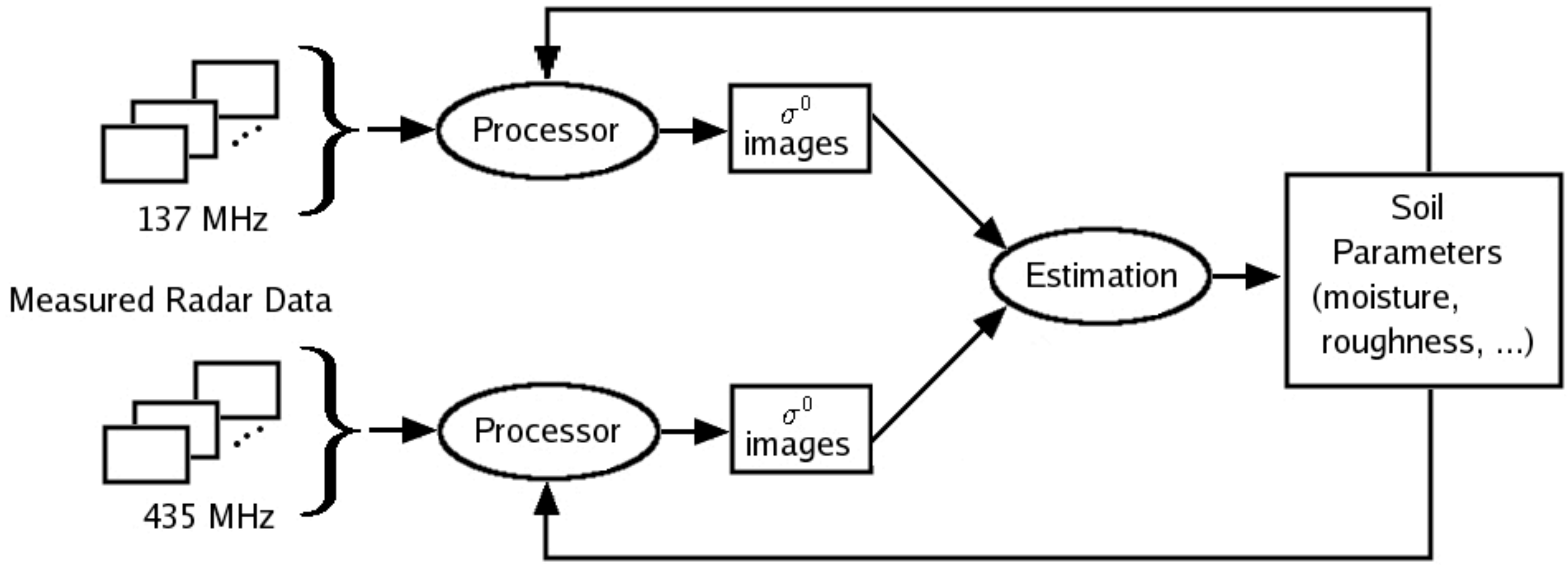
Typical Measurement Scenario



- Measure at 137 MHz, 435 MHz at each antenna position
- 4 polarizations at each frequency
- Real and Imaginary parts for each sample, 1 nsec spacing
- 2000 nsec total time
- Calibration traces:
  DC level, H and V drifts
- More antenna positions are desirable, but will have to wait for next system upgrades to speed up the digital data acquisition system

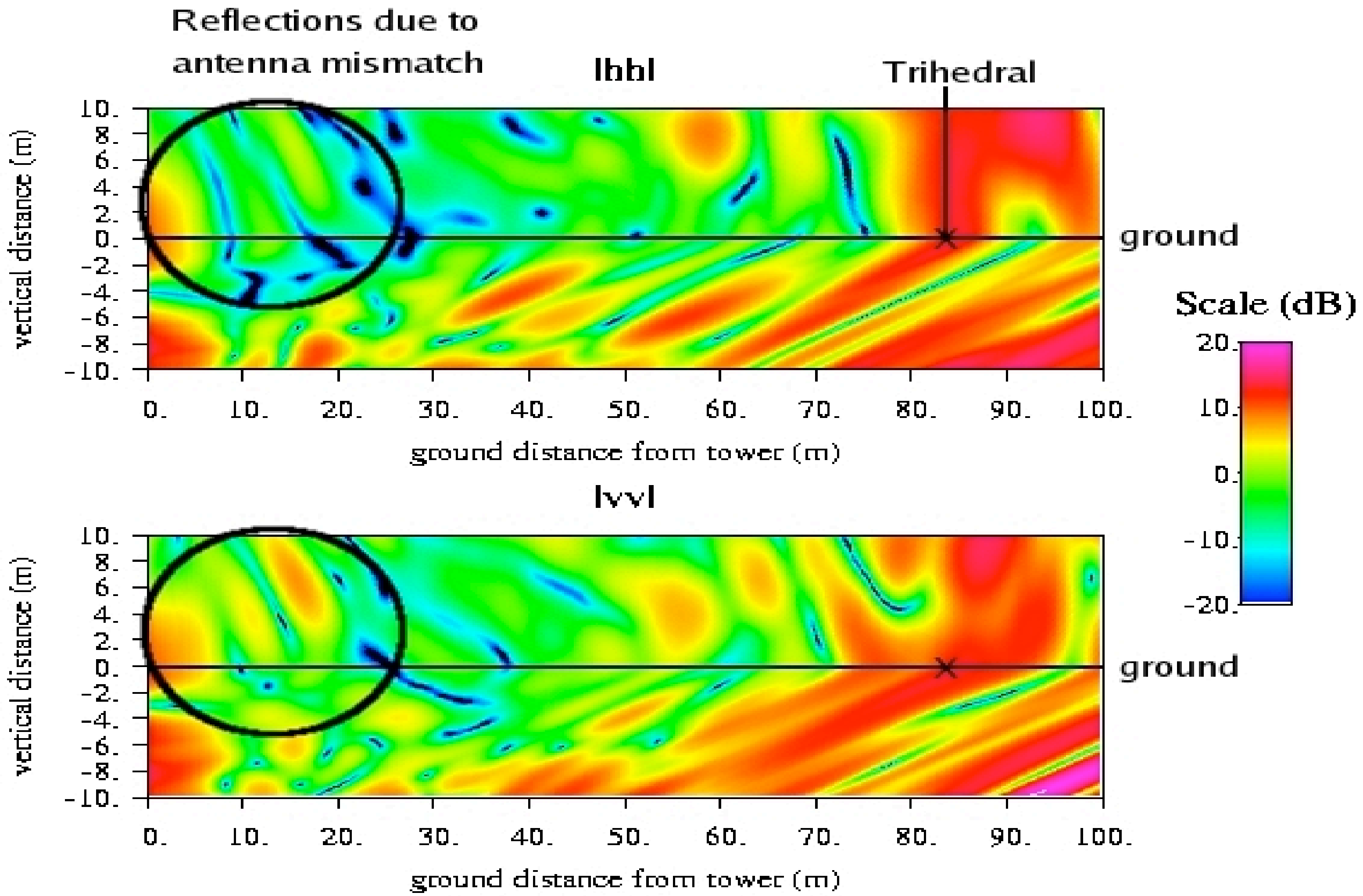
Tower Radar Integrated Processor

The New Approach



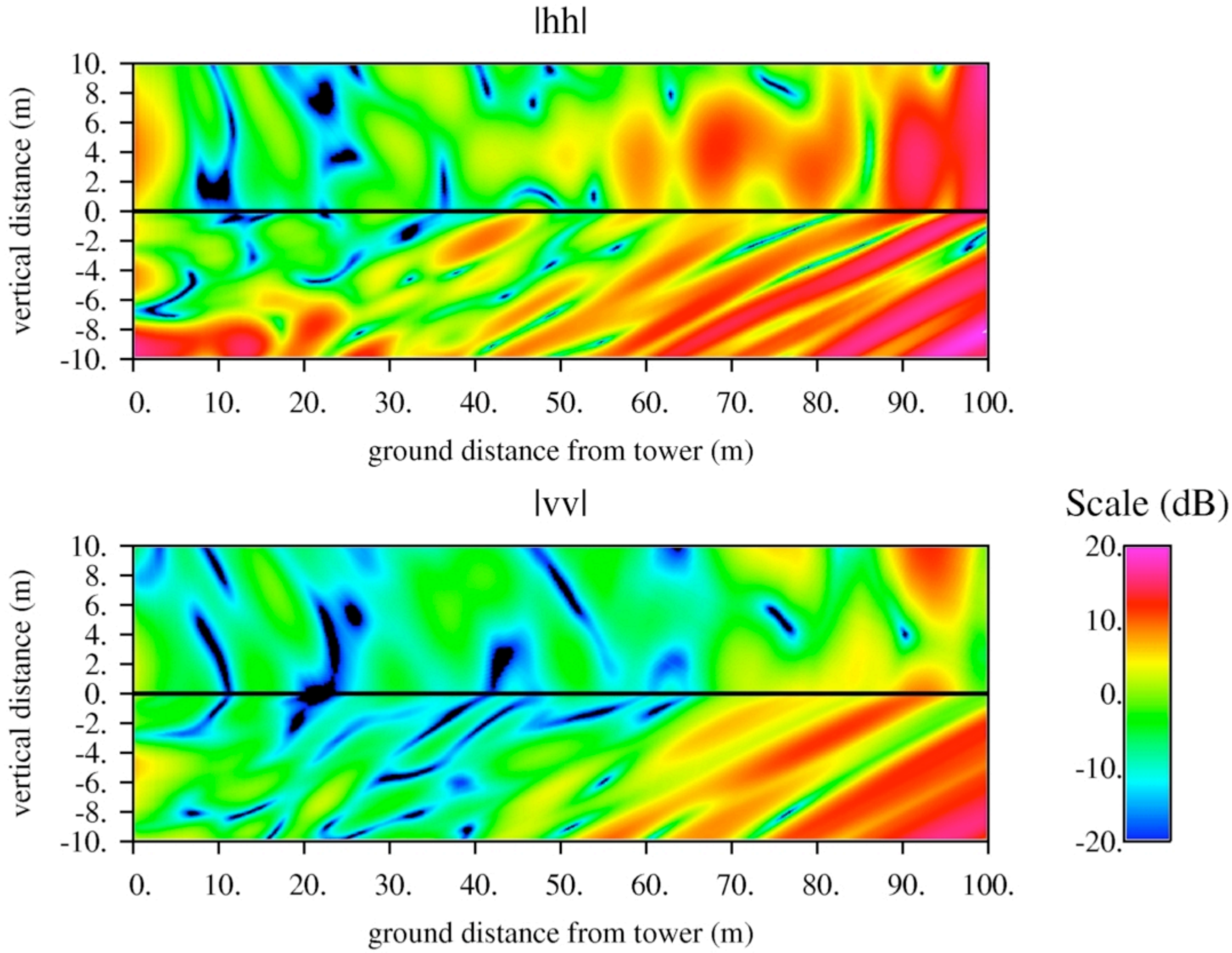
- Processor: time-domain into backscatter images
- Estimation: of soil parameters from images
- Feedback: wave speed in soil necessary to produce valid image data

Processed Data Example - First Iteration



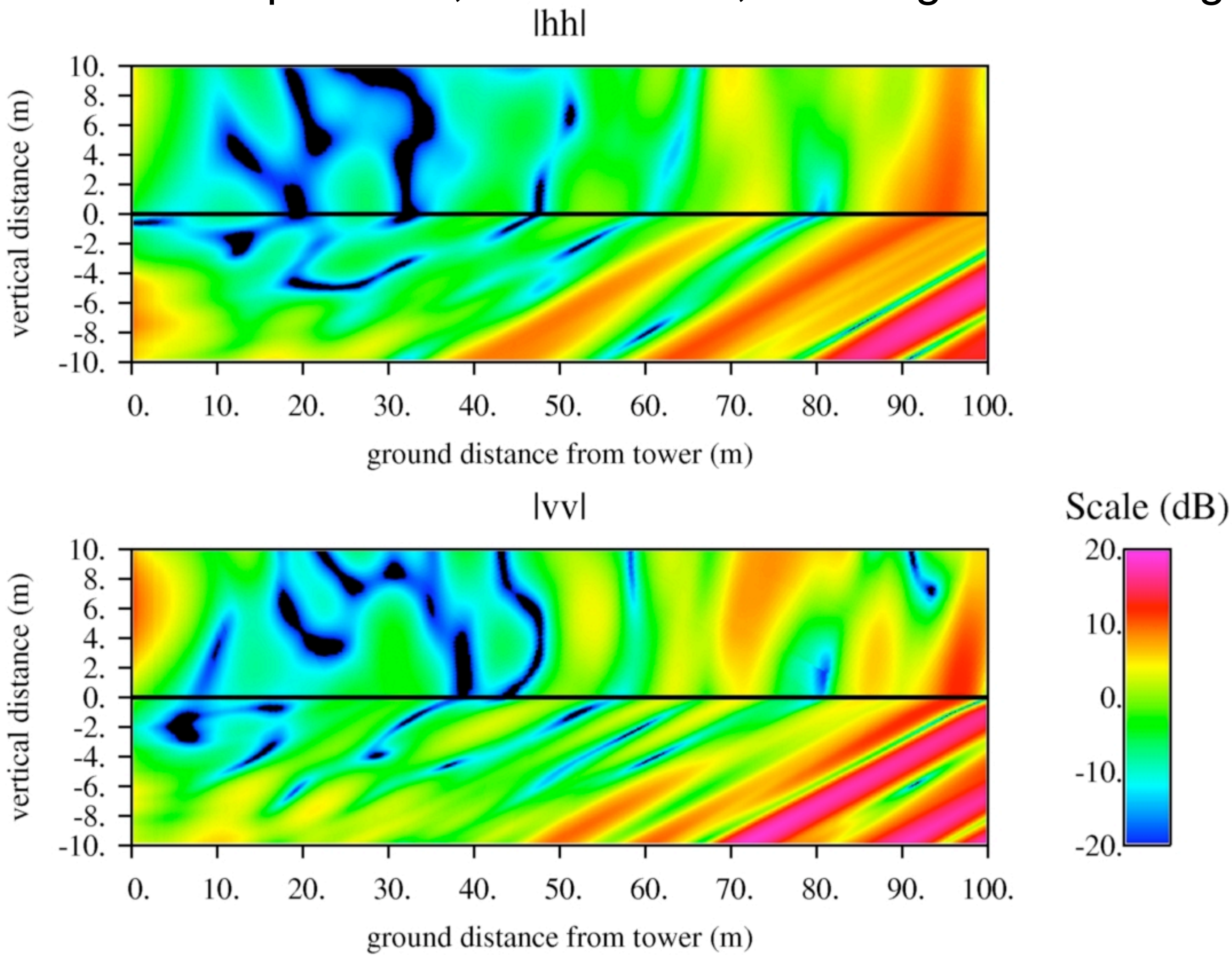
Integrated Processor: Soil Moisture Estimation Results

Arizona Experiment, Wet Ground, Converged VHF Images



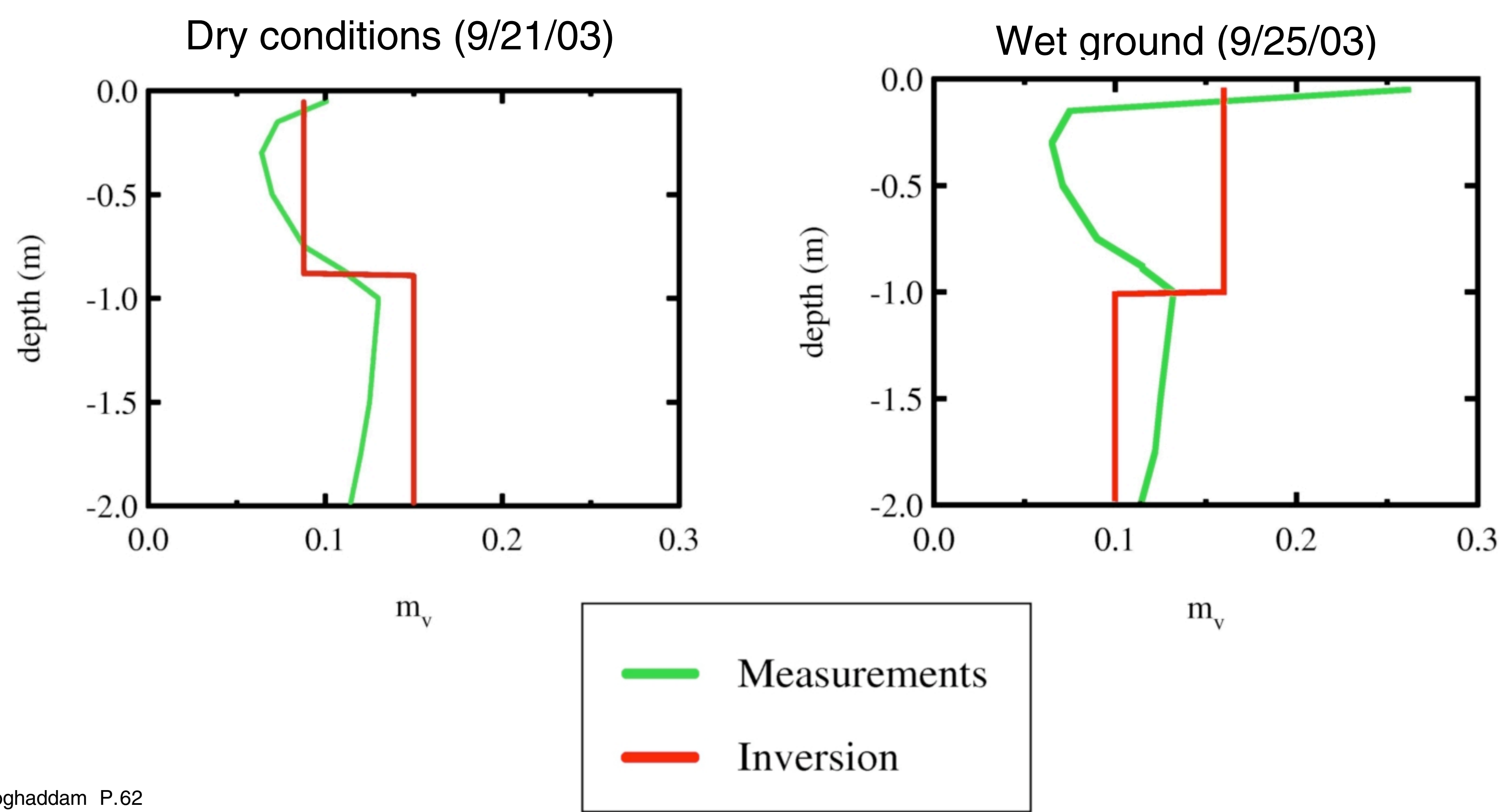
Integrated Processor: Soil Moisture Estimation Results

Arizona Experiment, Wet Ground, Converged UHF Images



Integrated Processor: Soil Moisture Estimation Results

Arizona Experiment, no vegetation

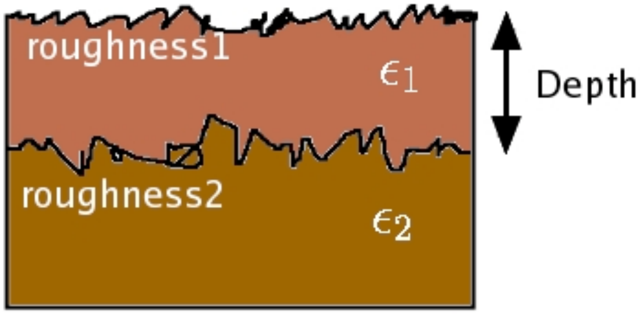


Integrated Processor: Estimation Results

Oregon Winter Experiment, Inversion Results

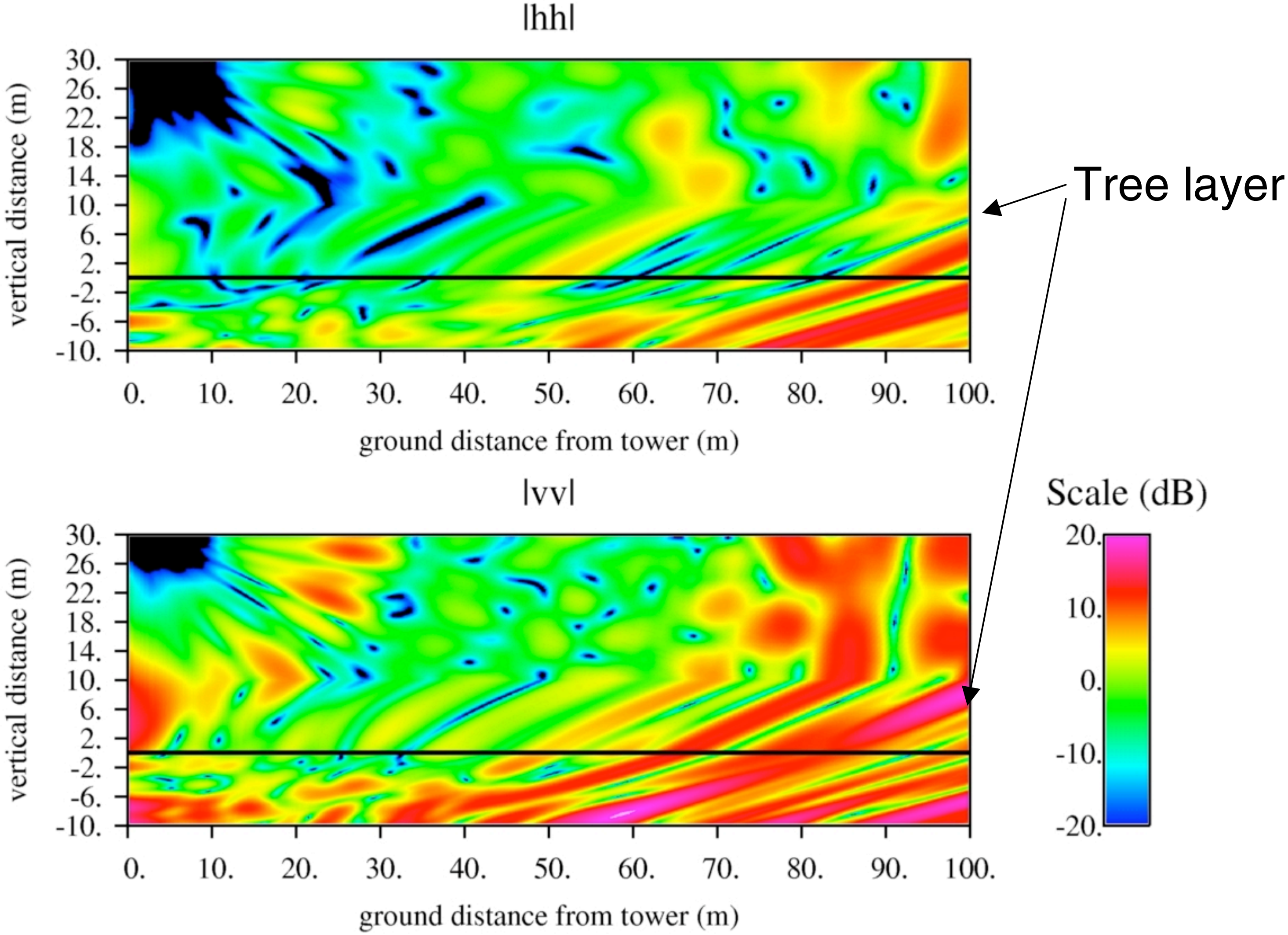
Inversion Results:

- Tree layer height: 12m
- Tree layer roughness: 35 cm
- Soil moisture (single layer): 0.15 volumetric
- Roughness estimate may be interpreted as rms height variation of trees
- Coherent scattering mechanism (double-bounce) have not yet been taken into account, and may change the soil moisture estimates significantly.



Integrated Processor: Estimation Results

Oregon Winter Experiment, Converged VHF Images



Summary and Observations

- Soil moisture estimation and processing algorithms have been successfully integrated, and the results generated are first of their kind
- Processing calibration issues have been successfully solved
- We have developed:
  - Analytical forward problems developed for layered soil
  - Numerical forward solution (FDTD) is developed but computationally very intensive
  - Nonlinear optimization implemented for inversion
- Future experiments are planned for soil moisture and other subsurface characterization experiments.

Science Analyses

Status: Science Algorithms and Analyses

Summary of Activities

- Ionospheric Effects and calibration (JPL)
- Assimilation studies (MIT)
- Effects of deep soil moisture information on improving estimates of partitioning of global water into various components, especially evapotranspiration and drainage (Boston University)
- Study of the interplay of soil hydrologic state and boreal carbon decomposition (Harvard University)

Summary of Ionospheric Effects Analysis

Results for UHF Frequency

Azimuth resolution reduction 1-50 times
Range resolution reduction is negligible
Image shift from few meters to 40m
Faraday rotation for UHF case can vary from 10-150 degrees
Large number of look angles to achieve the 1 km resolution at UHF will allow image formation with negligible ionospheric effect.

Results for VHF Frequency

Azimuth resolution reduction 40-200 times
Range resolution reduction is 2-5 times
Image shift from few meters to 300m
Faraday rotation for VHF case can vary from 60 to several multiples of 360 degrees.
At VHF, ionospheric effects are significant, but not detrimental for resolution.
At both frequencies, polarimetric scattering matrix can be used to estimate and remove the rotation angle

The system should ideally operate during periods of calm ionosphere.

Summary

- All stated goals were accomplished.
  - Hardware technology for dual-frequency stacked patch feed array at UHF/VHF was matured to TRL 5+. This included a scaled model and a full-scale prototype.
  - The 30-m antenna mechanical design was generated and feasibility established.
  - Mission scenario was developed to significant detail and cost estimates were generated.
  - Science data sets were generated and products were demonstrated.
  - Ionospheric effects were analyzed and their impact assessed.
  - Scientific impact of the proposed instrument and data products were shown and reinforced.
- **The MOSS mission overall was assessed to be feasible and the TRL-6 cutoff date needed to proceed to development could be very close**